ASTRONOMY

June 1983
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Telescopes Shown: *(top) Meade 8″ Model 2080 with optional photographic systems, including 4″ Schmidt-Cassegrain Photo-Guide Telescope; and (bottom) Meade 10″ Model 2120 with optional 2″ f/12 Photo-Guide Telescope.*

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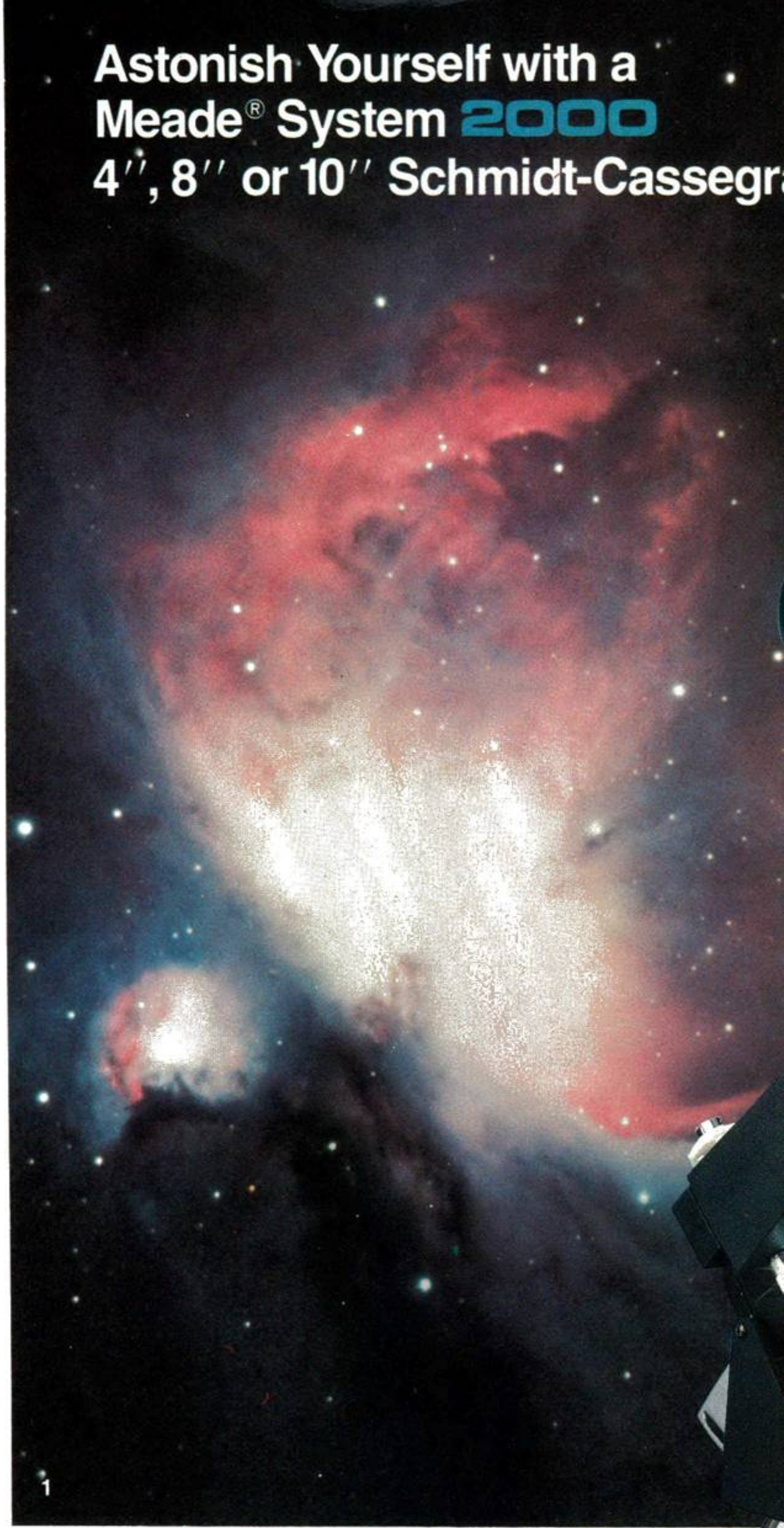

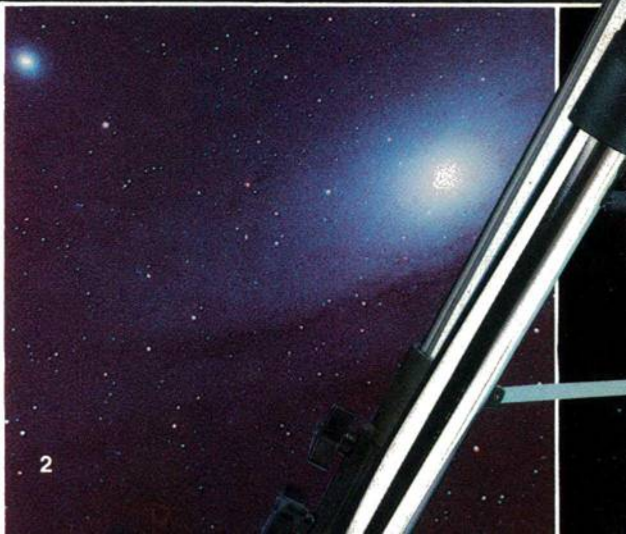

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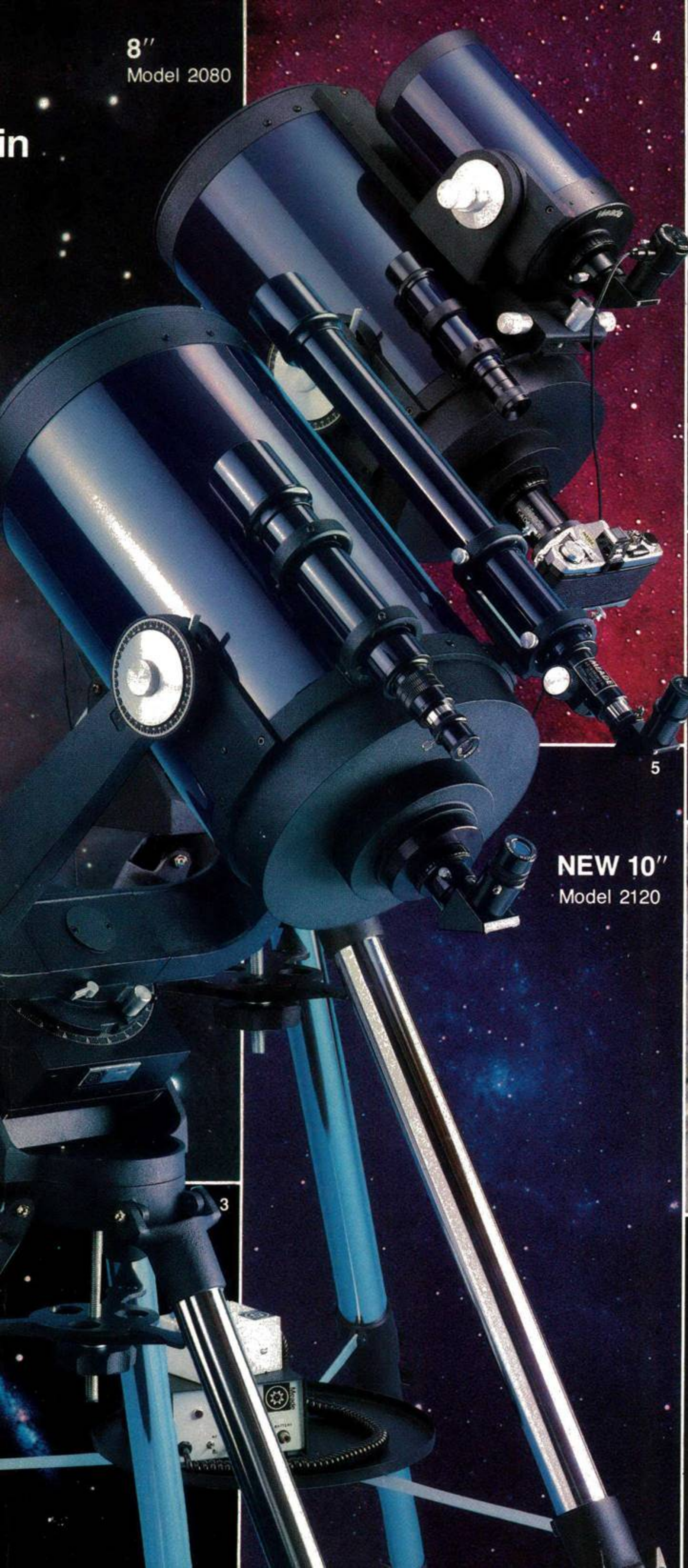

All astrophotographs shown on these pages were taken through off-the-shelf, unmodified Meade 8″ Model 2080 Schmidt-Cassegrain telescopes. For further technical details on these and many other astronomical photographs, send for your free copy of the Meade Schmidt-Cassegrain Astrophoto Brochure. (Alternately, the complete Meade 52-page General Catalog is available at $3.00 by First Class Mail and includes the Astrophoto Brochure at no additional charge.)

Key to Photographs
1, 2, 3, 5—Leo Henzl; **4, 7**—Emery Hildebrand; **6**—Paul Roques; **8**—John Sanford

1. Orion Nebula M42; exposure time 50 mins. **2.** Andromeda Galaxy M31; 60 mins. **3.** Galaxy M82; 60 mins. **4.** Milky Way in Sagittarius (50mm piggyback photo). **5.** Spiral Galaxy M33; 75 mins. **6.** Spiral Galaxy M51; 90 mins. **7.** Omega Nebula M17; 40 mins. **8.** Moon—Clavius region.

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Cover: The gas of the North America Nebula is set aglow by the light of newborn stars. But astronomers cannot hope to understand star formation without first examining the structure of such starclouds. ASTRONOMY examines the tricky business of astronomical surveying in this month's feature article. Photograph by Orien Ernest. These pages: The North America Nebula in its galactic context. The bright star is Deneb. Photograph by Alfred Lilge.

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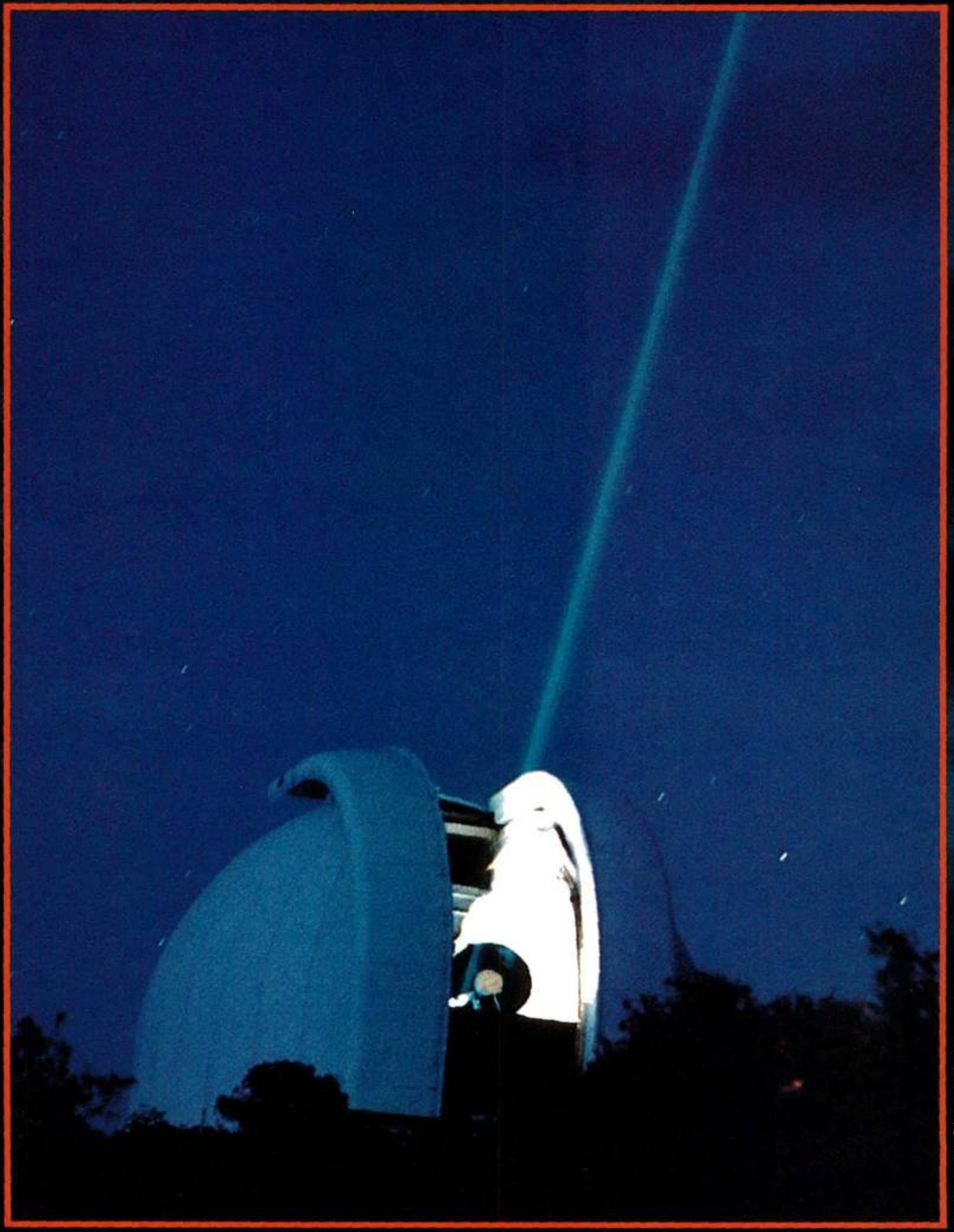
HOW FAR THE STARS

BY FRANCIS REDDY



McDonald Observatory

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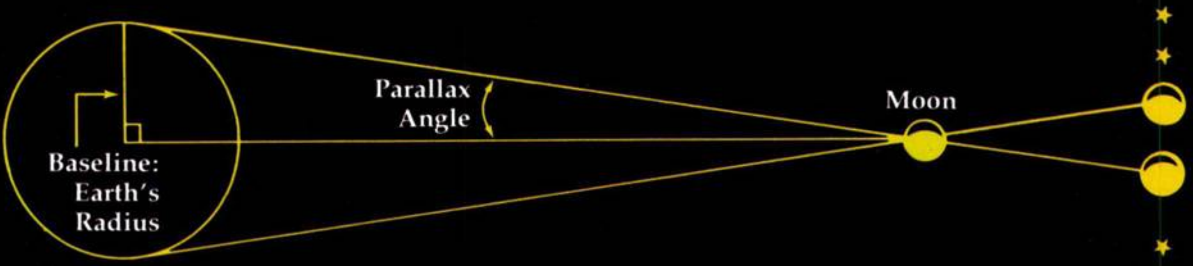
Kitt Peak National Observatory

Background photograph by Steve Reed

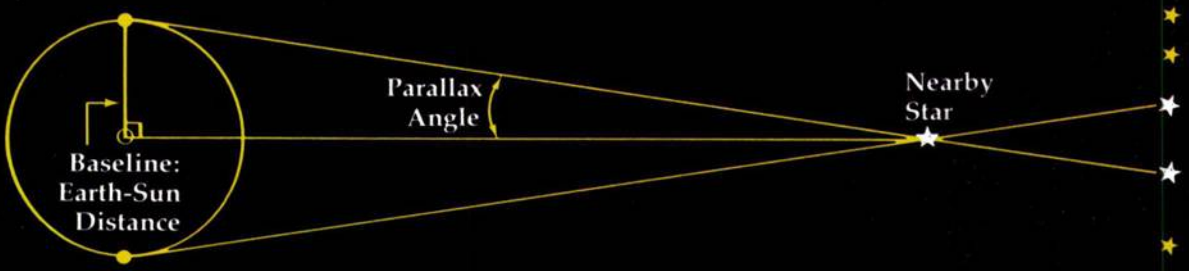
Surveying with Parallax

In Geocentric Parallax . . .


Parallax Angle
Moon
Baseline: Earth's Radius

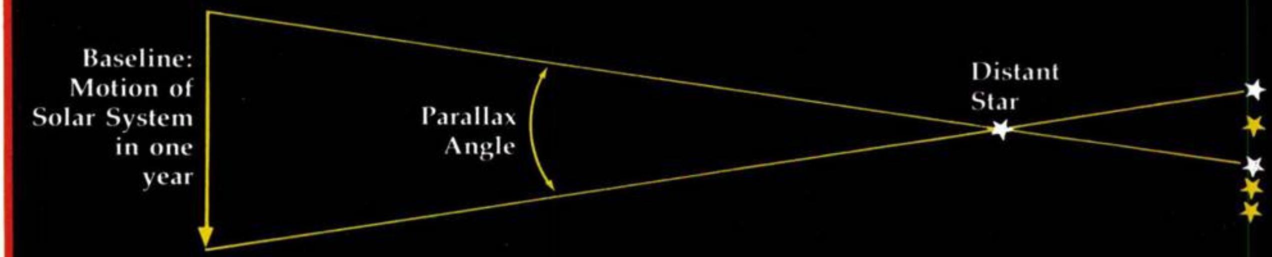
. . . the baseline is our planet's radius. Its rotation produces an apparent shift in close objects.

Heliocentric Parallax . . .


Parallax Angle
Nearby Star
Baseline: Earth-Sun Distance

. . . uses the Earth's annual motion to create the parallactic displacement of nearby stars.

Secular Parallax . . .


Baseline: Motion of Solar System in one year
Parallax Angle
Distant Star

. . . gives astronomers an infinite extension of the baseline, but it cannot be used to give accurate distances to individual objects.

While convalescing at a friend's riverside cottage, the narrator of Edgar Allan Poe's short story "The Sphinx" spies a horrible monster on the distant shore. The creature dwarfs the sparse trees, and taking the apparition to be a portent of his own death, the poor man understandably faints. He later describes the encounter to his host, who quickly assumes the precise position occupied by his shaken friend when the omen appeared; he soon locates the creature as it ascends a far-off hill. The beast is certainly remarkable, but he finds that its true size and distance were greatly exaggerated. For as the animal wriggles along a spider's thread, he sees that it is "about the sixteenth of an inch in its extreme length, and also the sixteenth of an inch from the pupil of my eye."

Poe may not have been thinking specifically about astronomical endeavors, but the central idea of "The Sphinx" serves well to illustrate astronomy's most critical variable — distance. The true brightness of a star, the mass of a molecular cloud, the real dimensions of a galaxy — all are critically dependent on an accurate measurement of distance.

Today, astronomers can determine the "propinquity" of objects in the solar system with extreme accuracy. Powerful radar pulses can be bounced off nearby planets, and the mathematical rigors of celestial mechanics provide data on smaller or more distant bodies. Yet the solar system is but a small fraction of the observable universe. Beyond our own star lie billions more, entwined in the complex of gas and dust that constitutes our Galaxy — itself just one of a seemingly endless number of stellar systems.

> *I remember his insisting very especially . . . upon the idea that the principal source of error in all human investigations lay in the liability of the understanding to underrate or to overvalue the importance of an object, through mere admeasurement of its propinquity.*
>
> *— Edgar Allan Poe,*
> *"The Sphinx"*

In order to fully examine the universe beyond the Sun, astronomers needed to devise techniques that could reliably determine enormous distances. The methods created to gauge the size of the cosmos utilize evidence as subtle as the motion of an individual star, the brightness of a distant sun, or the spectral fingerprint of a galaxy. Yet the most accurate means of ranging objects beyond the solar system involves a simple extension of a zoological phenomenon.

Many animals have evolved *binocular* vision, in which the visual fields of both eyes overlap. Predators must strike quickly and accurately in order to catch their prey, and binocular vision supplies them with a natural distance indicator. Each eye receives a slightly different view of an object because of the fixed distance that separates them, referred to as the *baseline*. This effect is easily demonstrated by experiment. Hold a finger at arm's length while successively blinking each eye — it will appear to pop back and forth relative to more distant objects in the background. Nearby objects are displaced more than those farther away, and a three-dimensional image is constructed when the brain combines the different testimony of each eye.

A nearby object, as seen from opposite ends of a baseline, appears projected on the background in a different place. This can be translated into an angle called the object's *parallax*. When numerical values for both the angle and the baseline are known, distance can be determined by simple trigonometry. Since the parallactic angle is dependent on both the proximity of the object in question and the length of the baseline used to make the observations, great distances can be measured by adopting a very long baseline. The trick, of course, lies in finding a baseline of the appropriate length.

The Earth's diameter is an attractive place to begin the search for a baseline because its diurnal rotation creates a parallactic shift in the positions of nearby objects — especially the Moon. Earth's companion is so close that it is displaced by nearly twice its apparent diameter in the sky. Observing the lunar parallax, however, is not as easy as it sounds. Astronomers must take into account the Moon's rapid orbital motion, as well as the refractive effects of Earth's atmosphere.

More accurate methods have supplanted geocentric parallax, but the technique is of considerable historical importance. In 1577 the Danish observer Tycho Brahe shattered 15 centuries of tradition by showing that a bright comet was more distant than the Moon, not an atmospheric phenomenon, as Aristotle had suggested.

Solar parallax is much smaller than the Moon's — only 8.8 arcseconds — but its measurement was especially important since it enabled astronomers to determine the radius of the Earth's yearly orbit. This distance, known as the astronomical unit, is equal to about 150 million kilometers — and marks the first step toward the stars.

Unfortunately, the method of geocentric parallax cannot penetrate beyond the solar system — not even very far into it — but the same principles can be employed if the radius of the Earth's orbit is known. Just as geocentric parallax took advantage of the Earth's rotation, so *heliocentric parallax* uses our planet's annual motion around the Sun to induce a positional shift in the nearer stars. When observations are made six months apart, the baseline becomes the diameter of Earth's orbit, or two astronomical units. But the heliocentric parallax of a star is always defined as having a baseline of *one* astronomical unit, or half the maximum observable displacement. Once the extent of a star's positional shift is determined, trigonometry again comes into play.

While it sounds straightforward enough, astronomers could only dream of measuring the minute parallax of a star until the middle of the last century. In 1838, Friedrich Bessel observed a tiny annual displacement in the position of the star 61 Cygni that amounted to nearly 0.6 second of arc, or 1/3000 the apparent diameter of a Full Moon. The star's 0.3-arcsecond parallax reveals it to be a close neighbor of the Sun at a distance of 700,000 astronomical units, or about 105 trillion kilometers.

Obviously, conventional units of distance are too cumbersome for application to even the nearest of stars. New and somewhat exotic units of measurement are

The Pleiades (above) and the Hyades (left) — moving clusters in constellation Taurus.

needed in order to ward off ridiculously large numbers. Once the speed of light was found to be a constant 300,000 kilometers per second, the *light-year* was introduced as a unit of distance equal to the nine trillion kilometers traversed annually by any uninterrupted photon.

A more useful unit, however, is derived directly from the technique of heliocentric parallax. A star at a distance of 3.26 light-years exhibits a parallax of one second of arc; thus the term *parallax-second* — *parsec* — was coined. With this unit in hand, astronomers can obtain a star's distance in parsecs merely by finding the reciprocal of its parallax. Bessel's 61 Cygni lies at a distance of 1/0.3 or 3.4 parsecs — about 11 light-years. There is actually no star within one parsec of the Sun; our star's nearest neighbor is the triple-star Alpha Centauri system, 1.3 parsecs distant.

Annual parallax is a powerful tool, a logical extension of principles discovered by the first surveyors, but it does have limits. The technique depends on accurately measuring those tiny displacements in a star's position induced by Earth's motion around the Sun, but at large distances parallax becomes exceedingly small. Minor errors inherent in the measuring process pile up inexorably as range increases. And at a distance of about 100 parsecs, the probable error of a given measurement is as large as the measurement itself — the information is virtually useless. In fact, obtaining reasonably accurate distances out to 30 parsecs with this method requires great care and precision. A still longer baseline is needed in order to probe beyond the Sun's neighborhood.

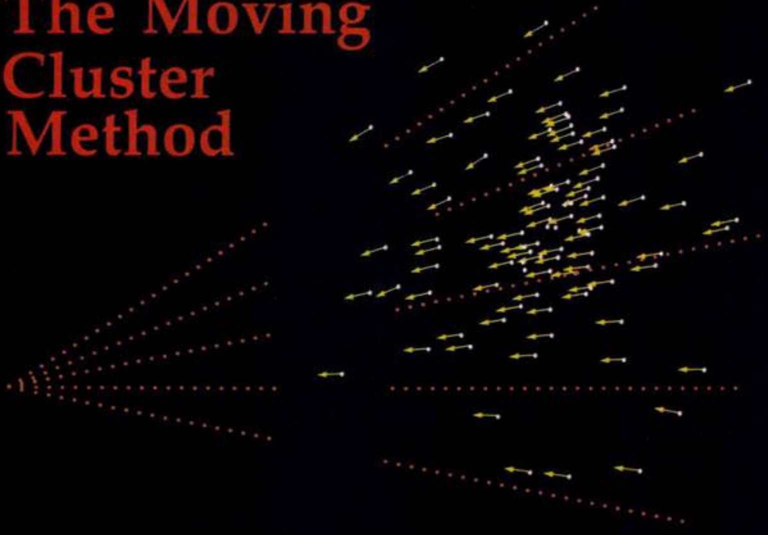
Fortunately, the Sun is as restless as the Earth. The motion of our solar system through the Galaxy induces its own apparent displacements in stellar position. The solar system hurtles toward a point in the constellation Hercules at a rate of about 20 kilometers per second, or nearly four astronomical units each year. Since extremely distant background stars will show a negligible shift, astronomers can find parallax by comparing photographs of a star field taken several years apart. Distance is again determined trigonometrically.

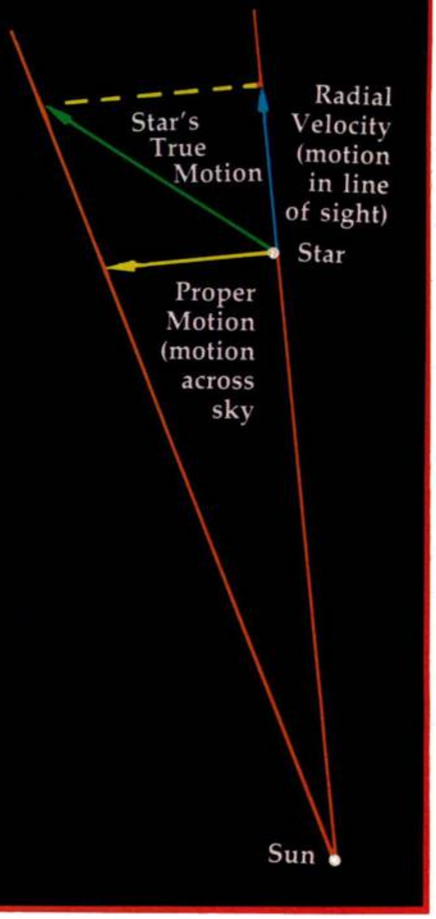
This *secular parallax* sounds like the star surveyor's dream — time alone provides an infinite extension of the baseline. But other suns, too, are restless. Individual stellar motions muddle the parallactic shifts and spoil the utility of secular parallax over long time intervals. So the displacement of a single star could be caused by either the star's *proper motion*, its real movement through the Galaxy across our line of sight, or the apparent movement created by secular parallax. For individual stars, this parallactic movement cannot be distinguished from proper motion.

In spite of this drawback, solar motion can be used to find *average* distances to groups of related stars, such as all stars of a certain spectral type. Considered as a whole, the individual motions of the group's members tend to cancel each other out — only the mean secular parallax of the sample is left. The distorting effects of individual stellar motions are thus minimized by studying these objects.

A range-finding technique closely related to secular parallax actually makes use of proper motion — the *moving cluster* method. The density of stars in an open cluster is so high that its members form a gravitationally

The Moving Cluster Method




Radial Velocity (motion in line of sight)
Star's True Motion
Star
Proper Motion (motion across sky
Sun

As the Sun and the Hyades cluster move apart in space, the stars appear to converge. When the convergence angle, radial velocity, and proper motion are measured, astronomers can then find the cluster's distance.

bound, dynamically stable unit. As the cluster moves, all of the stars within it share a common motion and follow parallel tracks through the Galaxy. If the system is fairly close to the Sun, perspective effects will appear to make these tracks diverge from or converge toward some point in space for the same reason oncoming highway traffic appears to diverge from some point on the distant horizon. One converging open cluster, the Hyades in Taurus, is a cornerstone of techniques for astronomical distance determination. It also provides a good example of how the method works.

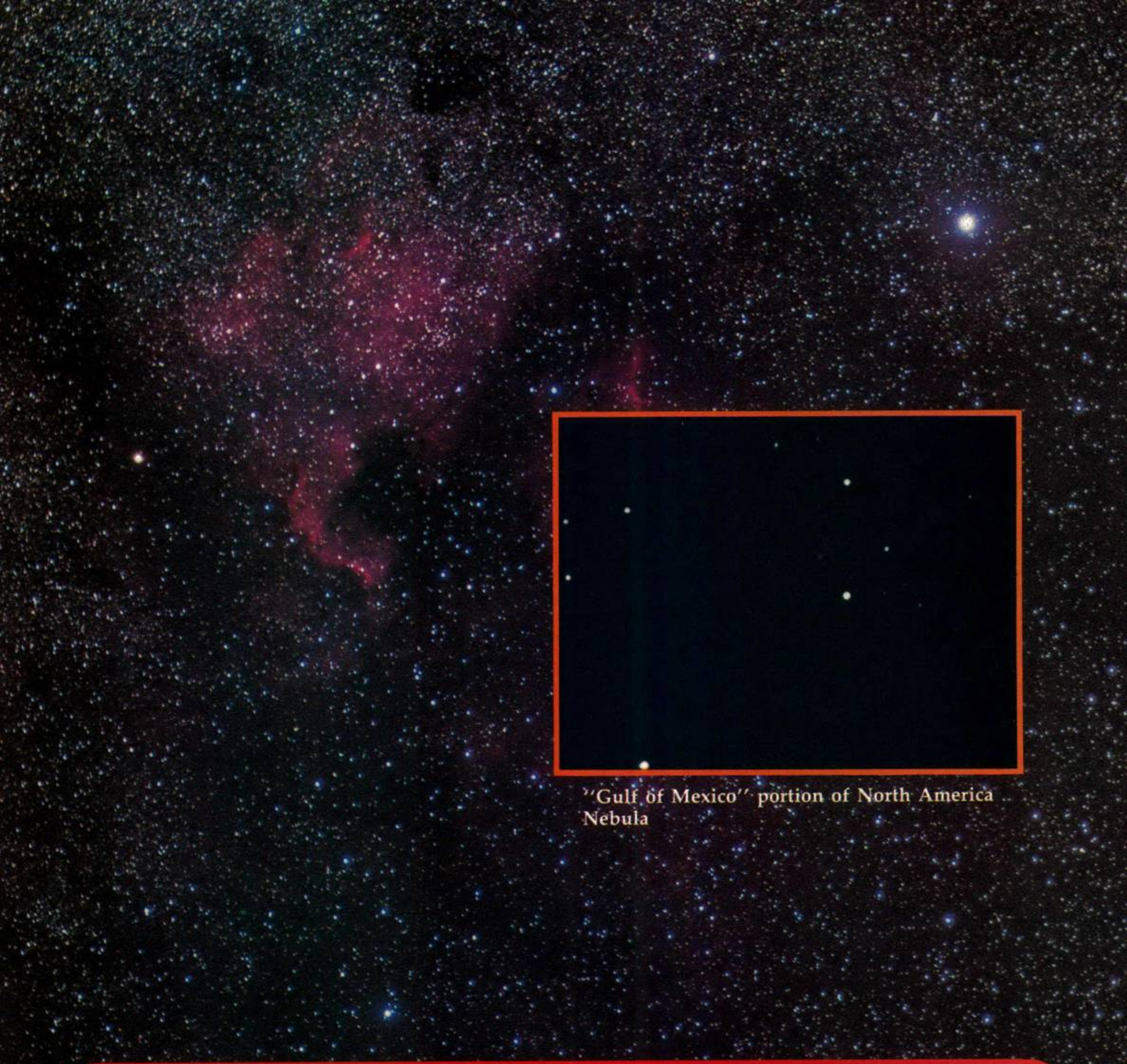
The actual motion of a star in space can be broken down into two components. One component moves across our line of sight (proper motion), and the other moves toward or away from us (radial velocity). To find the distance to a star in the Hyades with the moving cluster method, astronomers need its proper motion, the angle between the star and the point of convergence, and the star's velocity toward us. Proper motion is determined by observing the star's position over several years. The angle between the star's position and the point of convergence is also a straightforward measurement. Radial velocity, however, requires a look at the star's spectrum.

In 1842 the Austrian physicist Christian Doppler found a mathematical relationship between the frequency of a sound and the relative velocities of its source and an observer: a sound produced by a rapidly moving source would have a higher pitch when moving toward an observer and a lower pitch when moving away. Doppler predicted that a similar effect would hold for light waves, suggesting that a star's color indicated its motion in our line of sight — blue stars moving toward us, red stars away from us. The French physicist Armand Fizeau corrected Doppler in 1848, pointing out that the positions of emission and absorption lines in a star's spectrum would shift, not its color. At any rate, the velocity of a star along our line of sight is determined by comparing this spectral line shift to the line's wavelength as measured in a laboratory. A *Doppler shift* toward the blue end of the spectrum indicates motion toward Earth; a redshift means motion away from us.

Armed with all the necessary information — proper motion, radial velocity, and the star's angle to the convergence point — astronomers once again use trigonometry to get a value for the star's parallax, which is then converted to a distance in parsecs. When the values for many cluster stars are taken together, the average distance to the cluster is obtained. It was not until 1908 that the American astronomer Lewis Boss used the moving cluster technique to find the Hyades distance, now thought to be about 45 parsecs. Another bright cluster in Taurus, the Pleiades, shows a moving cluster parallax that places it 128 parsecs away.

The moving cluster method has an uncertainty of 5 to 20% within 500 parsecs. But ten times farther out, at around 5 kiloparsecs (kpc), the proper motion of the cluster is too small to measure with precision and the uncertainty increases to 50%. Even within this limit, large errors can creep in if some of the measured stars don't belong to the cluster. Yet 5,000 parsecs isn't enough to probe across the diameter of our own Galaxy, let alone the universe beyond it.

Unfortunately, we have reached a dead end — the moving cluster method is the last technique we use that's



"Gulf of Mexico" portion of North America Nebula

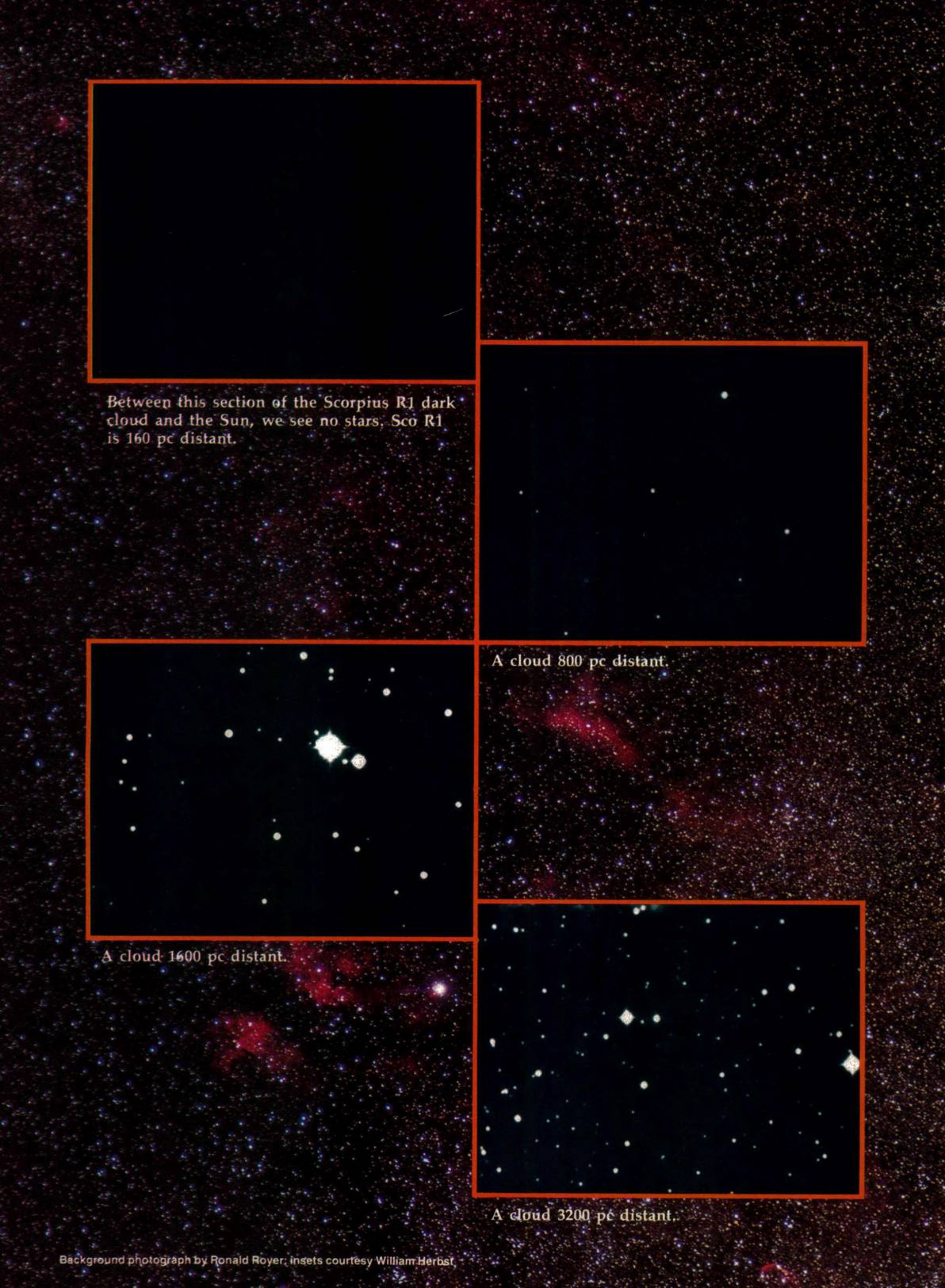
Star Counts and Dark Clouds

To understand the physics of star formation, astronomers need an accurate distance to stellar nurseries. Spectroscopic parallax cannot be used reliably, because the young stars found within these molecular clouds often have unusual spectra. Since it makes no assumptions about the embedded stars, star counting offers an independent check on distances derived from spectroscopic methods.

Take, for example, the case of the North America Nebula, a region of ionized hydrogen associated with a dark molecular cloud. William Hiltner of the University of Michigan argued in 1956 that its distance was one kiloparsec, based on the spectroscopic parallax of a star he assumed was exciting the nebula. But in 1980 several astronomers found a highly obscured star that *they* took as the exciting star. Using infrared observations, they derived a distance of 200 parsecs for the nebula, making it one of the closest regions of star formation known. Depending on whom you believed, the North America Nebula was either twice as far off as the Orion complex or only half of its distance!

In 1981 Taft Armandroff and William Herbst of Wesleyan University used a technique entirely different from spectroscopic parallax — they counted stars. If the cloud is sufficiently dense, the only stars observed should be foreground objects, since no background stars can show through. To find a distance, they simply compared the density of stars projected onto the nebula with the predicted number of stars as a function of distance. Distant clouds should have more stars projected on a given area than nearby clouds. This is illustrated by the inset photographs, which show an area of the same size on several different clouds.

Armandroff and Herbst first calibrated the star-count technique by testing it on molecular clouds whose distances were well determined. The Wesleyan astronomers then tackled clouds with unreliable distances, including the North America Nebula. Their findings agreed with the older distance of about 1 kpc, but decide for yourself — how far away *is* the North America Nebula?



Between this section of the Scorpius R1 dark cloud and the Sun, we see no stars. Sco R1 is 160 pc distant.

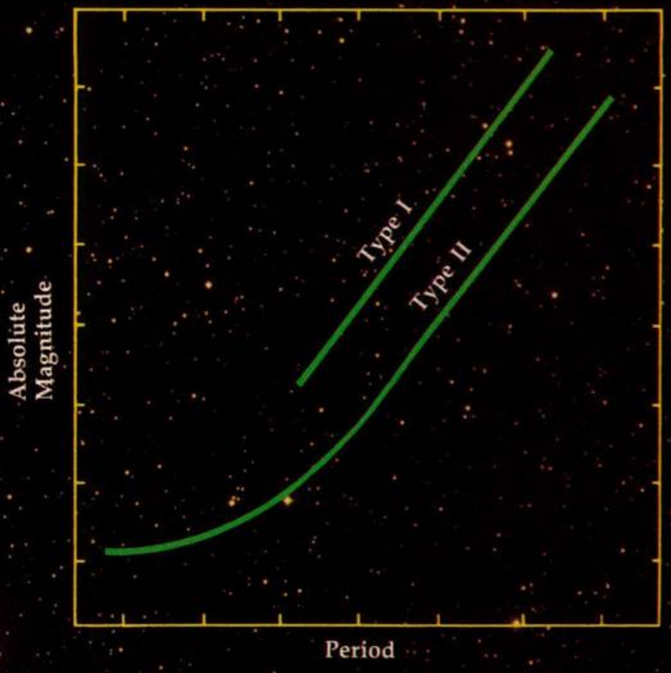
A cloud 800 pc distant.

A cloud 1600 pc distant.

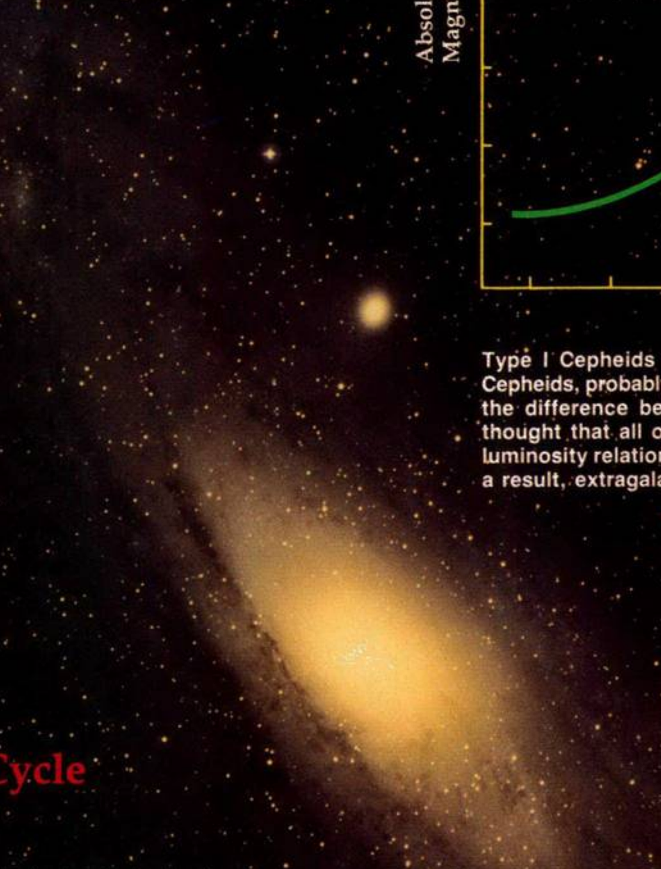
A cloud 3200 pc distant.

Background photograph by Ronald Royer; insets courtesy William Herbst

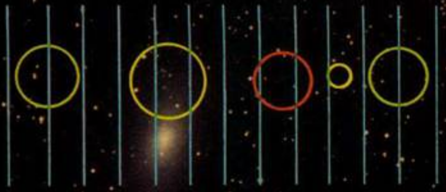
The Period Luminosity Diagram



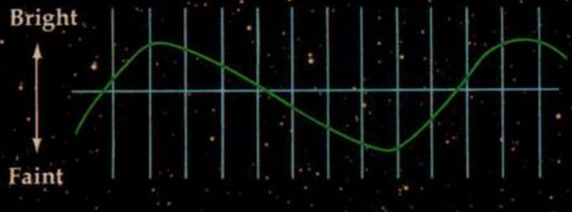
Type I Cepheids are four to six times brighter than Type II Cepheids, probably due in part to their higher metal content. Until the difference between Cepheids was realized, astronomers thought that all of these pulsating stars followed the period-luminosity relation now assigned to the fainter Type II stars. As a result, extragalactic distances were underestimated.



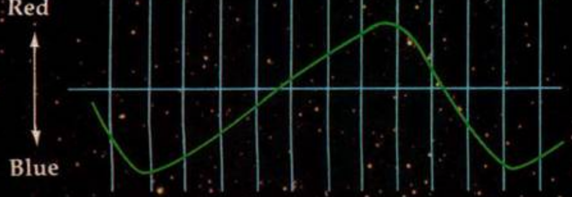
A Cepheid's Cycle



A typical Cepheid undergoes change in size and color (top), brightness (middle), and radial velocity (bottom). At maximum light, the star is at its bluest color — yellow-green — and highest surface temperature.



The star's radius is largest between maximum and minimum light when brightness decreases, smallest in the opposite part of the cycle when luminosity increases. For clarity, the relative sizes are exaggerated; the actual change in size is usually around 10 percent and never exceeds 20 percent.



Radial velocity is determined by measuring the wavelength shifts of absorption lines in the star's spectrum. Changes in radial velocity are the result of the star's expansion (blueshift) and contraction (redshift).

California Institute of Technology photograph

based on *direct* measurement. The trigonometric methods create around the Sun a sphere of well determined distances several hundred parsecs in radius. Astronomers must search within this realm for the techniques that will take them beyond it. Here begins a progression of clever, but increasingly indirect, techniques of distance measurement. To venture farther from the Sun, astronomers must weigh the advantage of a greater working range against the disadvantage of lower accuracy.

Astronomical information comes to astronomers in the form of starlight, so it seems reasonable to look for a method of measurement that uses the properties of light. Electromagnetic radiation obeys an inverse-square law — a light source of given brightness will appear four times fainter if its distance is doubled. Thus a star will appear one-fourth as bright if we double its distance, one-ninth as bright if we triple it, one-sixteenth as bright if we move it four times farther away, and so on. With this inverse-square relation between the distance of a light source and its intensity, a star's distance could be determined if its intrinsic brightness were known.

The task of finding some relationship between apparent magnitude and distance would be simple if all stars were of equal intrinsic brightness. Unfortunately, differences in mass and age create enormous differences in intrinsic luminosity — from mighty stars 100,000 times brighter than our Sun to faint objects 10,000 times less radiant. *Absolute magnitude* is used to compare stars — by definition, absolute magnitude is the apparent brightness a star would have if it were 10 parsecs away. Since absolute magnitude is rooted to a fixed distance, it is a direct function of the star's intrinsic energy output and permits us to compare stars to each other.

If there were some way to identify stars of a given absolute magnitude, then the apparent intensity of starlight would be a valuable distance indicator. Fortunately, astronomers can estimate the surface temperature of a star by examining its spectrum. The cooler gas in a star's upper layers selectively absorbs light, and this absorption superposes dark bands on the star's rainbow-like continuum spectrum. These absorption lines are the signatures of chemical elements in the upper layers of the star.

Some stars, like Betelgeuse and Antares, have spectra loaded with the absorption lines of complex molecules; others display the far simpler spectra of a handful of elements. Since molecules break up at high temperatures, the stars with molecular spectra must be cool. Conversely, stars with the spectral lines of hydrogen and other elements must have surface temperatures too high for the formation of even the simplest molecules.

Spectral observations suggest that stars can be grouped into classes of like character and, presumably, stars that fall into the same spectral type have similar intrinsic luminosity — all we must do is calibrate them. The absolute magnitudes of various spectral types can be found by first examining those nearby stars whose distances are known from direct methods. These stars are then segregated into classes by their spectra. Now each spectral type has an associated absolute magnitude, and the method of *spectroscopic parallax* is calibrated for use with more distant objects.

The spectroscopic technique brings us out to 15 kpc — quite a leap from the limits of the moving cluster method. In principle, this use of "standard candles" permits the determination of any stellar distance as long as the star's spectrum can be observed. There are,

The Celebrated Cepheids

The star marked δ by Bayer, near the Head of Cepheus . . . is at its greatest brightness [for] about one day and thirteen hours.

— First report of δ Cephei's variability
John Goodricke, 1786

Are the "spiral nebulae" part of the Milky Way, or extragalactic objects? Edwin Hubble's 1923 discovery of Cepheid variables in M-31, the Andromeda Galaxy, should have settled the matter immediately, but the debate over the nature of spiral nebulae lingered into 1925. One of the reasons for continued argument was the controversy over the period-luminosity relation. The only reason for questioning the relation was that no one understood its physical cause.

Since about 1894, Cepheids were thought to be eclipsing binaries, bright stars whose much fainter companions regularly passed in front of them as seen from Earth. But how could the intrinsic brightness of a star be related to the orbital period of its companion? It just didn't make sense.

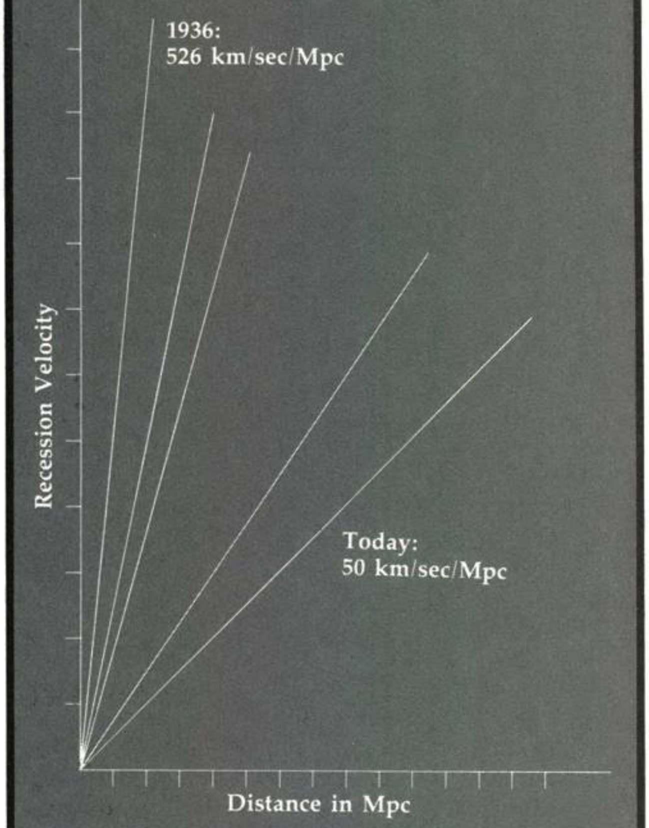
It made even less sense in 1914, when Harlow Shapley showed that any companion must orbit well *inside* the bright primary, because Cepheids are so large. "The explanation that appears to promise the simplest solution of most, if not all, of the Cepheid phenomena," wrote Shapley, "is founded on the rather vague conception of periodic pulsations in the masses of isolated stars." The hypothesis was considered "vague" because the internal structure of stars was unknown at the time.

Three years later, the British astronomer Arthur Eddington outlined the mechanical aspects of stellar pulsation. The size or amplitude of the pulsation decreases rapidly from the star's surface to its center because the star's central density is very high. This means that the center of the star is not involved in the pulsations, and the complex chemical and thermal conditions within it may be ignored. It also means that the energy source of the star — now known to be thermonuclear reactions within the core — cannot cause the pulsation.

Without a source of mechanical energy, a star's pulsations would damp out very quickly as frictional forces robbed it of energy. Somewhere near the surface of the star, Eddington suggested, lies a heat "valve" that powers the pulsations against frictional energy losses. Suppose that there is a zone near the star's surface where its atoms are partially ionized. When the star is hottest and most compressed, the partially ionized region traps heat because its atoms become opaque to radiation. This heat is released as mechanical energy that makes the star expand. The ionization zone becomes increasingly transparent to radiation as the star expands and cools. When the energy trapped by the ionization zone is used up, the star contracts and the cycle continues.

Eddington's stellar "heat engine" also provided an explanation for the period-luminosity relation. For any group of pulsating stars, the periods of the pulsation depend on the average density of the stars: large, distended stars have longer periods than small, compact stars. Since a star's brightness is also related to its size, both its pulsation period and its luminosity must also be related. Although modern models of stellar pulsation have changed some of the details, Eddington's basic ideas were correct.

The Hubble Relation



In 1929, Edwin Hubble announced a relationship between a galaxy's recession velocity and its distance. Astronomers have recalibrated Hubble's relationship several times through the years. For example, a given object with a recession velocity of 500 km per second was considered 1 Mpc distant in 1936. Its distance doubled in the early 1950s, and by 1960 its range increased again to 2.8 Mpc. Another revision in 1968 pushed it out to 6.8 Mpc; today astronomers using Hubble's relation as their measuring rod would find the object to be more than 9.5 Mpc distant.

however, several drawbacks. Starlight is absorbed and scattered by interstellar gas and dust on its journey to Earth, which makes distant stars appear both redder and fainter than they really are. Depending on the amount and density of the dust through which the starlight passes, interstellar extinction can be quite severe. A typical value for the extinction of a star's light in the Milky Way is 0.8 magnitudes per kiloparsec — for every thousand parsecs from Earth, a star will appear half as bright as it would without the dust. Thus a star's dust-dimmed luminosity causes astronomers to overestimate its true distance.

Spectroscopic parallax only works well for stars of certain spectral type. One important astronomical consequence of this selectivity is that we are highly uncertain about the distances to areas where stars are born. The size, mass, density of electrons, and chemical composition of star-forming molecular clouds are the data upon which scenarios for star formation are accepted or rejected. In turn, the determination of these quantities demands an accurate distance. The most accurate means of finding the distance to a cloud is the spectroscopic parallax of stars known to be associated with it. But many molecular clouds have only a few visible stars associated with them, if any at all. And even when embedded stars are found, they often have peculiar spectra that make them useless in determining distances.

At its best, spectroscopic parallax has an uncertainty of about 20 percent. Beyond about 15 kpc, the probable error increases to 50 percent and, again, the information gleaned by spectroscopic methods is essentially useless. Another technique is needed.

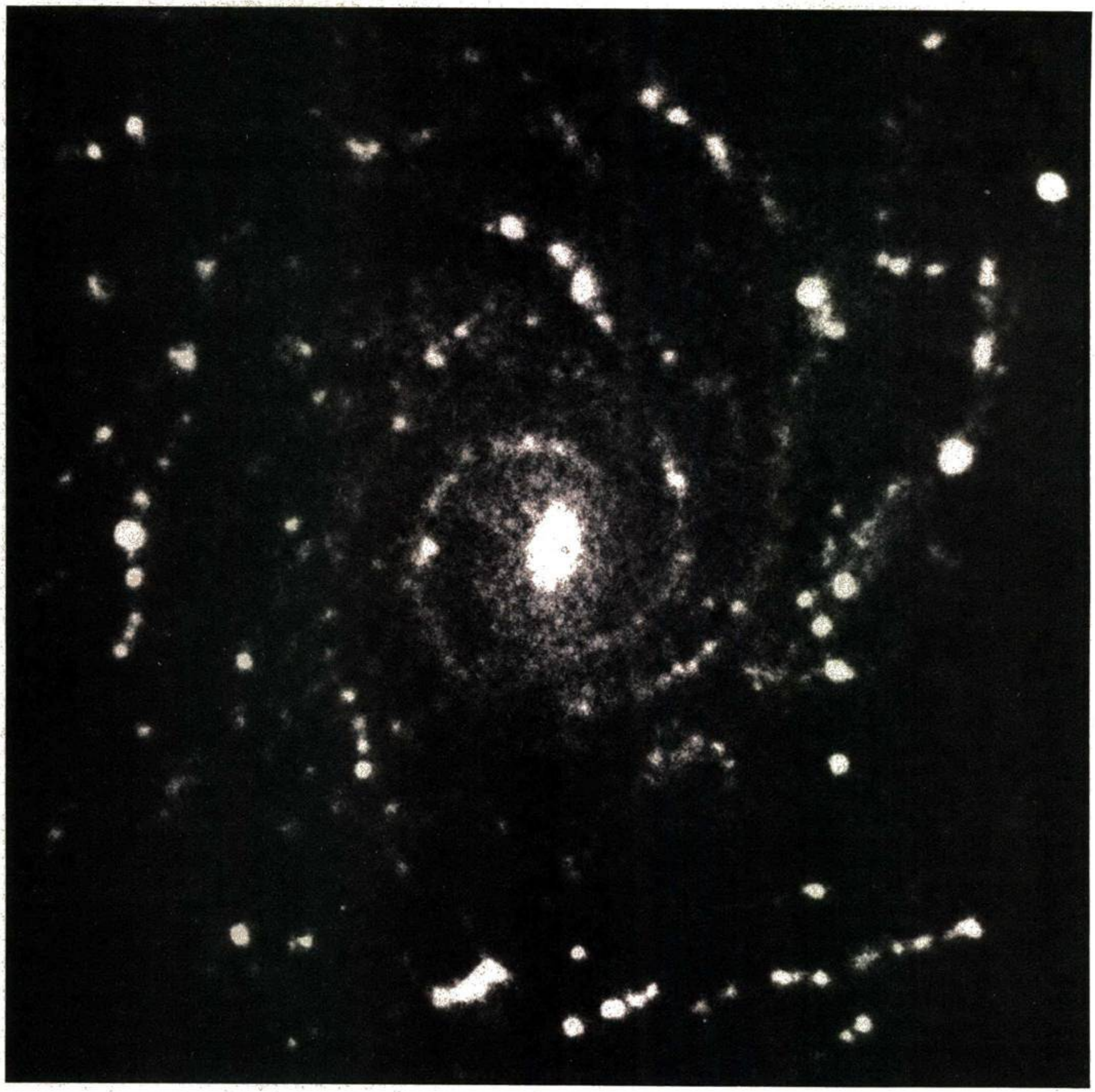
Perhaps the best standard candle for long-distance surveying was recognized in the early years of this century through studies of the Milky Way's two satellite galaxies, the Magellanic Clouds. Harvard College built an observatory in Peru to survey the southern skies, and in 1908 a research assistant working on this data found variable stars in the Small Magellanic Cloud that displayed an important property. Henrietta Leavitt found that the brightest Cepheid-type variables were those with the longest time between minimum and maximum brilliance. Leavitt pursued this correlation, and by 1912 she had established a direct relationship between the period of a Cepheid and its apparent brightness.

For astronomical surveyors, this property of the Cepheids becomes a powerful tool for measuring distance. The depth of the Magellanic Clouds is much smaller than their distances from us, so all of the stars within them are at essentially the same distance. Leavitt's work suggested that the period of a Cepheid correlates with its *absolute magnitude* — that is, its intrinsic luminosity — since distances to all Magellanic Cloud Cepheids could be considered identical. Once the distances to Cepheid variables within our own Galaxy were found by independent methods, the period-luminosity relation for these stars would be the best standard candle. Of course, this sounds much easier than it turned out to be.

First of all, no Cepheids are close enough for heliocentric parallax to give a reliable distance. In fact, the nearest Cepheid is Polaris, the North Star, about 200 parsecs distant. The next best possibility for calibrating the period-luminosity relation depends on finding Cepheids within open star clusters whose distances are known. Provided that all Cepheids in the universe behave the same way — not an unreasonable assumption — then knowing the distances and periods of a few Cepheids transforms Leavitt's relation between period and apparent magnitude to one of period and *absolute* magnitude. If you could find a Cepheid anywhere in the universe, and record its period and maximum brightness, you could determine its distance.

In 1916 another Harvard astronomer, Harlow Shapley, calibrated the period-luminosity relation to find disances for the Magellanic Clouds (now considered to be about 55 kpc distant), and our Galaxy's entourage of globular clusters (found at distances up to 60 kpc). By 1924 Edwin Hubble of Mount Wilson Observatory had identified several Cepheids in both the Andromeda Galaxy (M-31) and M-33 — the first conclusive evidence that these "spiral nebulae" were extragalactic objects. Using Shapley's period-luminosity curve, Hubble's work indicated that the Andromeda spiral was at least 300 kpc distant. Today this stellar system is thought to lie some 700 kpc away. Why the discrepancy?

Unfortunately, one of the assumptions made about Cepheids was that they all behaved similarly. In fact, there are really *two* types of these variable stars. Prior to 1950, metal-poor Cepheids (Type II) were used in finding distances within the Milky Way and out to the globular



Red filters emphasize a galaxy's HII regions — one key to the distant universe. Courtesy Paul Hodge.

clusters. For these stars, the period-luminosity relation was correctly calibrated. But the Cepheids found in other galaxies are often metal-rich (Type I), and in the 1950s astronomers realized that these stars were really four to six times brighter than the Type II Cepheids used for calibrating the relation. This meant that all previous estimates of extragalactic distances had to be doubled, while distances within the Galaxy remained the same.

The revision of the period-luminosity relation had many important implications. For instance, M-31 must be somewhat larger than the Milky Way, and the globular clusters surrounding it must be comparable in brightness to those around our own Galaxy. The recalibrated relation also cleared up a few thorny problems. Formerly, the Milky Way's ionized hydrogen regions seemed roughly twice as large as those in the Magellanic Clouds and nearby galaxies. The new distance scale eliminated this discrepancy. The differences in size between Galactic and extragalactic stellar associations showed a similar improvement.

Once the period-luminosity relation was calibrated, astronomers had a powerful tool of long-range (out to 4,000 kpc) and tolerable uncertainty (10-30 percent). This is a good point to start using megaparsecs (Mpc) — millions of parsecs — rather than kiloparsecs. M-31 and M-33 are both about 0.7 Mpc distant. At about 4 Mpc even Cepheids at maximum light are too faint to detect and the method becomes useless. Cepheids take us some three million times farther than the Sun's nearest neighbor, and they provide the most reliable means of finding distances within the Local Group, the cluster of nearby galaxies that includes our own. These regular variables are not, however, the only kind of star able to serve as standard candles.

Violent stellar outbursts called *novae* seem to have a limited range in brightness. Surveys of novae in galaxies with well determined distances enable astronomers to derive a relationship between a nova's maximum brightness and its change in brightness as a function of time. As with the Cepheids, this sort of relation allows astronomers to find the absolute magnitudes of new novae, which in turn indicate distance. At maximum brightness, novae can be detected out to 10 Mpc. Although less reliable as distance indicators than the Cepheids — an uncertainty of 25 percent is considered quite good — novae are useful as checks on the distances found by other methods.

Supernovae are far brighter than novae, and thus can be detected at greater distances. These powerful events are not merely stellar outbursts, but full-fledged explosions that herald the deaths of massive stars. Supernovae exhibit a large range in absolute brightness, however, and they cannot be used as reliable standard candles until astronomers know more about the source of individual differences. Nevertheless, the great luminosity of supernovae enables astronomers to identify them as far out as 100 Mpc, a fact that makes them invaluable distance indicators in spite of their low accuracy — the probable error is anywhere from 25 to 50 percent.

Beyond 4 Mpc, the Cepheid detection limit, astronomers are stuck in a sort of twilight zone where all of the available distance indicators have large uncertainties. From here on out, an uncertainty of 30 percent is the best we can do. In order to obtain the best possible accuracy, several of these rough indicators are used in combination.

Areas of ionized hydrogen (H II regions) can be identified in distant spiral and irregular galaxies. With the effective range of the Cepheid method, both the intrinsic brightness of a galaxy and the sizes of its H II regions can be determined independently. These studies show a rough correlation between a galaxy's absolute magnitude and the diameters of its largest H II regions. Once the correlation is known, the apparent magnitude of a galaxy of unknown distance and the size of its largest H II regions permit a determination of distance.

This technique is somewhat controversial. The physical reasons for such a diameter-luminosity relation remain unknown, and recent measurements indicate that the correlation isn't really very good. So while the method works as long as H II regions can be distinguished (about 60 Mpc), it can be applied only to those galaxies rich in gas — namely, loose, open spirals and irregular systems.

H II regions are not the only portions of galactic anatomy recognizable at large distances. Globular clusters surround many galaxies, including our own. If the brightest globular clusters of distant galaxies have the same absolute magnitudes as those that orbit the Milky Way, they can be used to find distances. Judging by the apparent brightness of globular clusters around its most prominent member, the giant elliptical galaxy M-87, the great Virgo cluster of galaxies lies about 15 Mpc distant — just about the limit of this method's effective range. Of course, this assumes that the globulars around other galaxies are similar in age, mass, structure, and chemical composition to those surrounding nearby galaxies. If this assumption is not valid, then the distance to M-87 and the whole Virgo cluster is wrong.

Astronomers can penetrate even farther into the universe — perhaps 100 times farther — by locating the brightest galaxy in a cluster of galaxies. Most of the known galaxies are elliptical systems, huge agglomerations of aged stars containing little gas and dust. Many of the stellar systems in rich clusters of galaxies are elliptical, and so are the brightest members. The brightest ellipticals in these clusters apparently have very similar absolute magnitudes, and this small variation transforms the brightest cluster galaxies into distance indicators. Again, the apparent magnitude of a cluster's brightest elliptical galaxies gives away its distance.

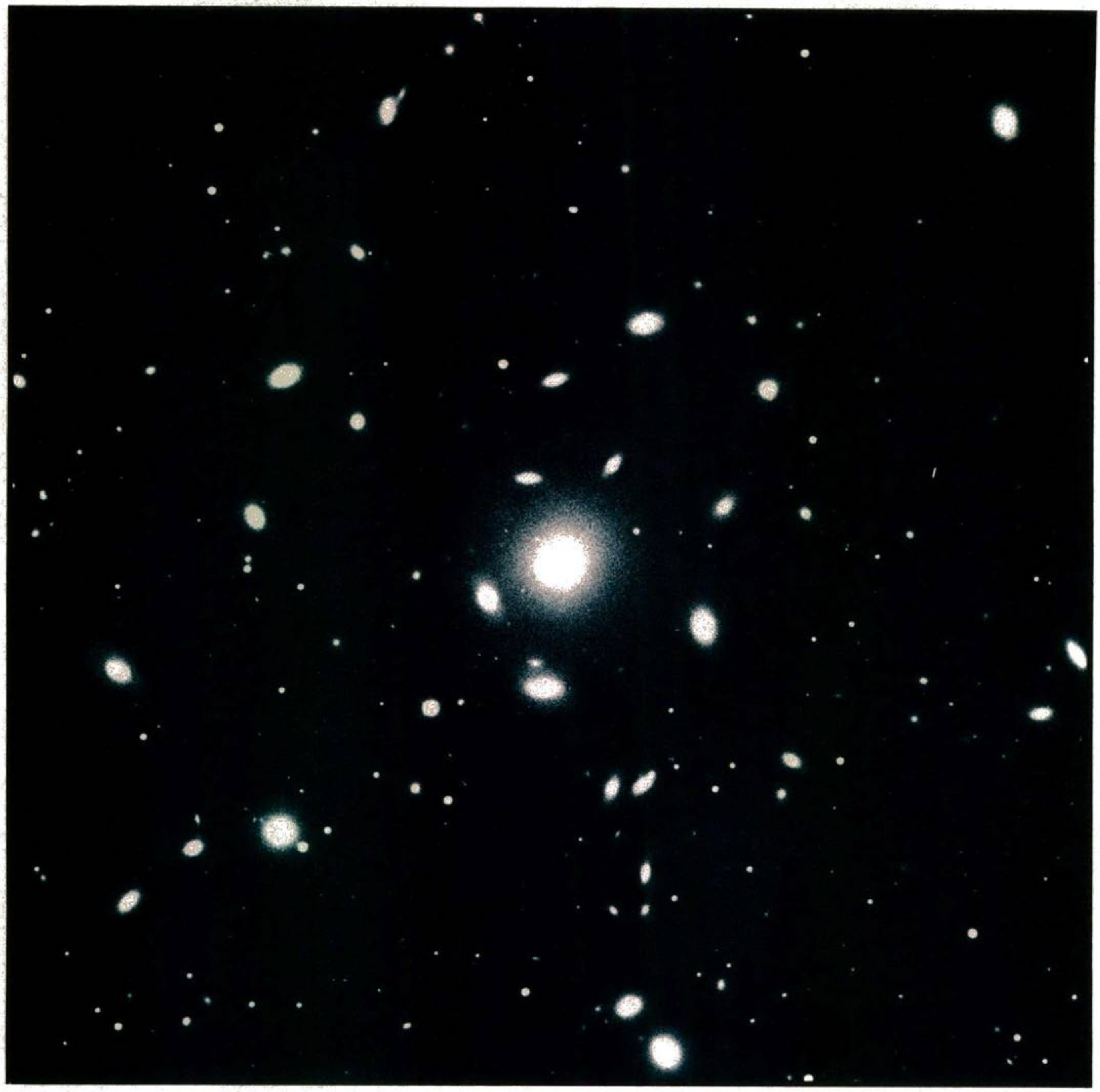
Between 10 and 1,000 Mpc, the typical uncertainty of this technique is considered less than 50 percent — but no one knows how much less. If distances beyond several hundred megaparsecs are considered fairly good estimates, distances greater than 1,000 Mpc are little more than good guesses. Our line of sight to an object at any distance is a column of space that contains everything between Earth and the object in question. In light of our growing uncertainty regarding large distances, the problem of absorption by intergalactic matter attains great importance when we consider a column of intergalactic space 1,000 Mpc (3 billion light-years!) in length.

There is some overlap in all of these techniques, which gives astronomers the opportunity to cross-check the distances found by any particular method. No large discrepancies have cropped up, which suggests that intergalactic dust is not a serious problem. Recently, though, astronomers using the 300-meter radio telescope in Arecibo, Puerto Rico, discovered a large cold cloud of hydrogen gas not associated with any galaxy. Astronomers believe the cloud is about 10 Mpc distant and may be a proto-galaxy that never formed stars. Until this discovery, astronomers considered intergalactic space practically void of matter. While the evidence for the cloud's existence is not yet conclusive, intergalactic absorption could be important for distant objects whose light passes through the tenuous outer regions of similar clouds.

One more measurement technique remains. Just as the radial velocities of stars can be found with their spectra, so the spectra of galaxies indicate their velocity with respect to the Sun. In 1912 Vesto Slipher of Lowell Observatory managed to obtain spectra of the Andromeda Galaxy that showed a Doppler shift. When he measured the blueshift in the spectral lines, Slipher reached the startling conclusion that this galaxy was approaching the Sun at a velocity of 300 km per second — the greatest velocity that had been observed in astronomy. By the late 1920s, Slipher had measured the radial velocities of 40 spirals; nearly all of them showed spectral lines shifted toward the red end of the spectrum, indicating that almost every galaxy was moving away from us.

Finding accurate distances to spirals was still a difficult business, even after the discovery of Cepheids within them. Although radial velocities for 40 galaxies were known, Hubble had obtained distances to only 18 of them by 1929. In spite of his small sample, he presented strong evidence for a clear relationship between a galaxy's redshift and its distance. Since redshift is a function of an object's velocity away from us, Hubble actually claimed a relationship existed between a galaxy's recession velocity and distance. According to Hubble, the more distant the galaxy, the greater its rate of motion away from us. The entire universe was apparently expanding.

When Hubble graphed galactic recession velocities as a function of distance, the relation appeared linear; thus velocity equals distance multiplied by some numerical

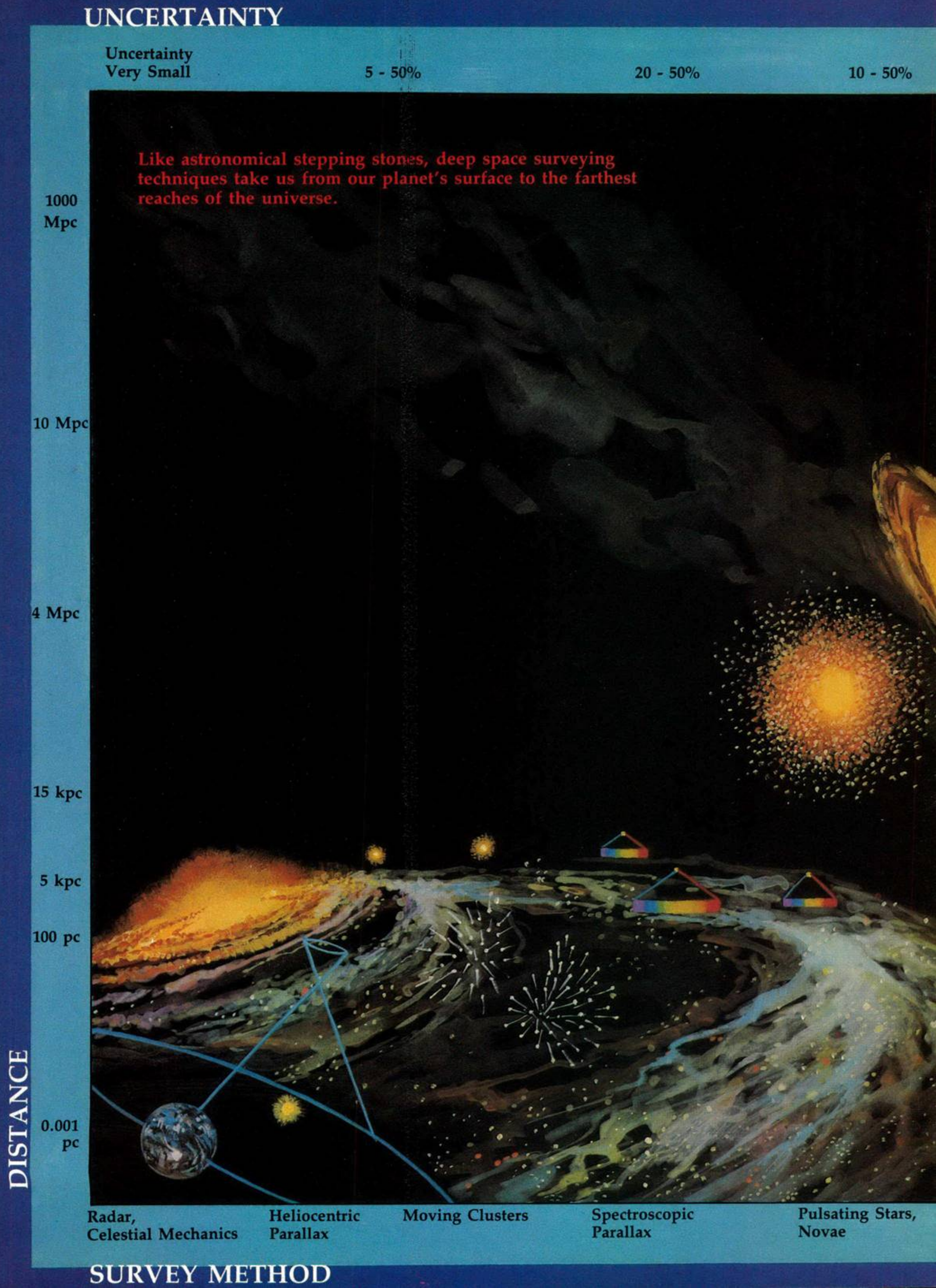


At least 1000 galaxies make up this cluster in Coma Berenices, 120 megaparsecs — 400 million light-years — distant. Kitt Peak National Observatory photo.

constant. This number, since called Hubble's constant or *H*, is the slope of the line Hubble found when he plotted the recession velocities of galaxies by their distances; the constant is expressed in units of velocity/distance, or kilometers per second for each megaparsec. In 1936, after several years of refinement, Hubble published his final conclusions: the Virgo cluster is 2.3 Mpc distant, and the value of the constant is 526 km per second per Mpc.

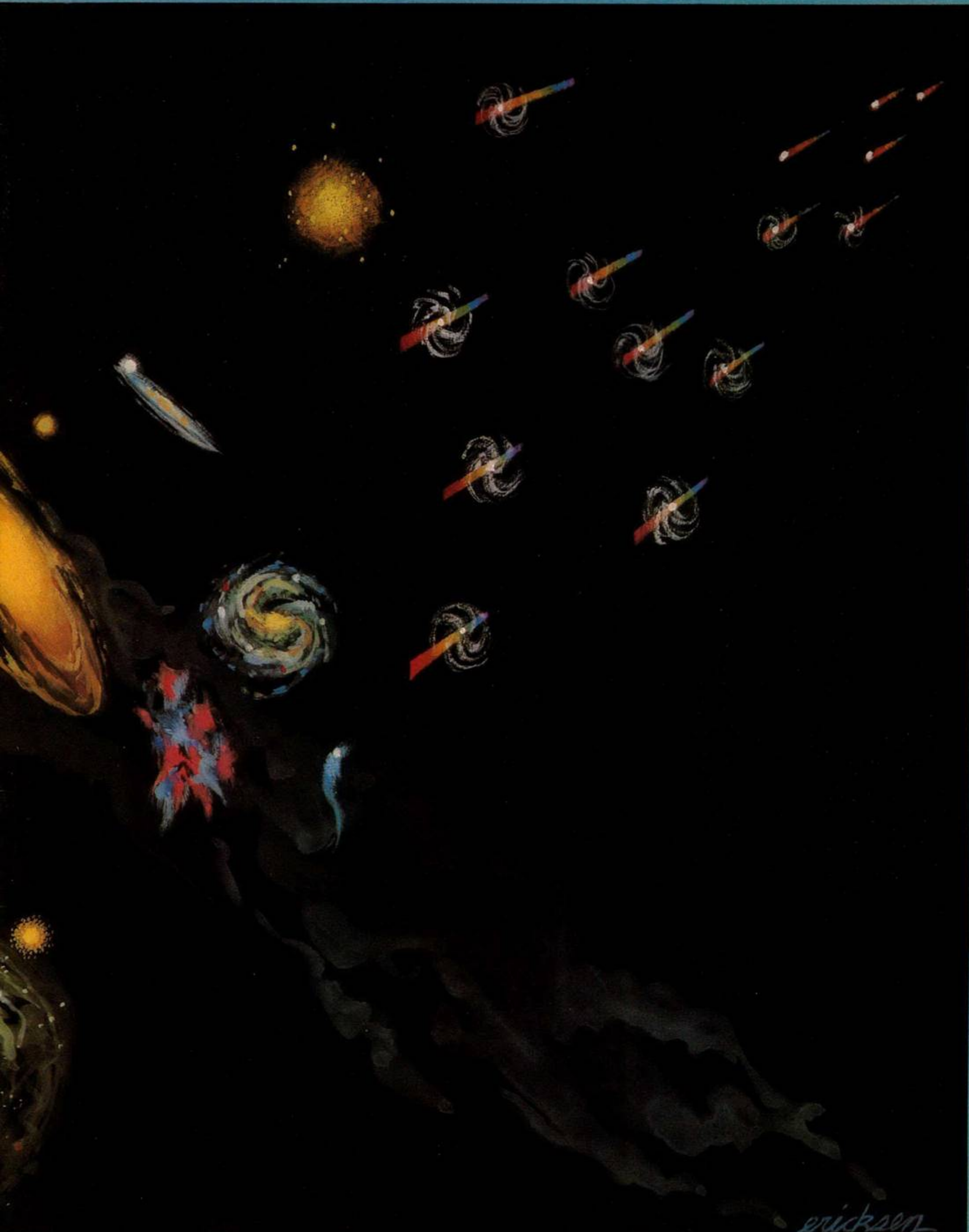
With the revision of the Cepheid period-luminosity diagram in the early 1950s, distances within the Local Group doubled, and the value for *H* fell to half that of Hubble's. It fell again in 1956 — down to 180 km per second per Mpc — when an extensive new survey of radial velocities was published. Two years later, Allan Sandage of Mount Wilson Observatory reviewed Hubble's whole distance scheme. He found that several errors had been made along the way. Some of the brightest "stars" Hubble used to gauge distance were really H II regions or stellar associations. Hubble's proportionality constant fell yet again, down to 75 km per second per Mpc. With no effort on its own part, the universe had expanded by seven times in only 22 years!

Astronomers must know the value of Hubble's constant if the velocity-distance relationship is to be a useful surveying tool. The actual value of *H* is very difficult to determine. As noted before, the Andromeda Galaxy is moving *toward* us — it is so close that its individual motion wipes out the systematic redshift of expansion. Astronomers use galaxies beyond 10 Mpc to eliminate these local effects, but this is the realm where most measurement techniques have the greatest uncertainty. It is safe to say that the actual value for *H* probably lies between and 50 and 100 km per second per Mpc. Many researchers prefer a value of 55. Using this value, the edge



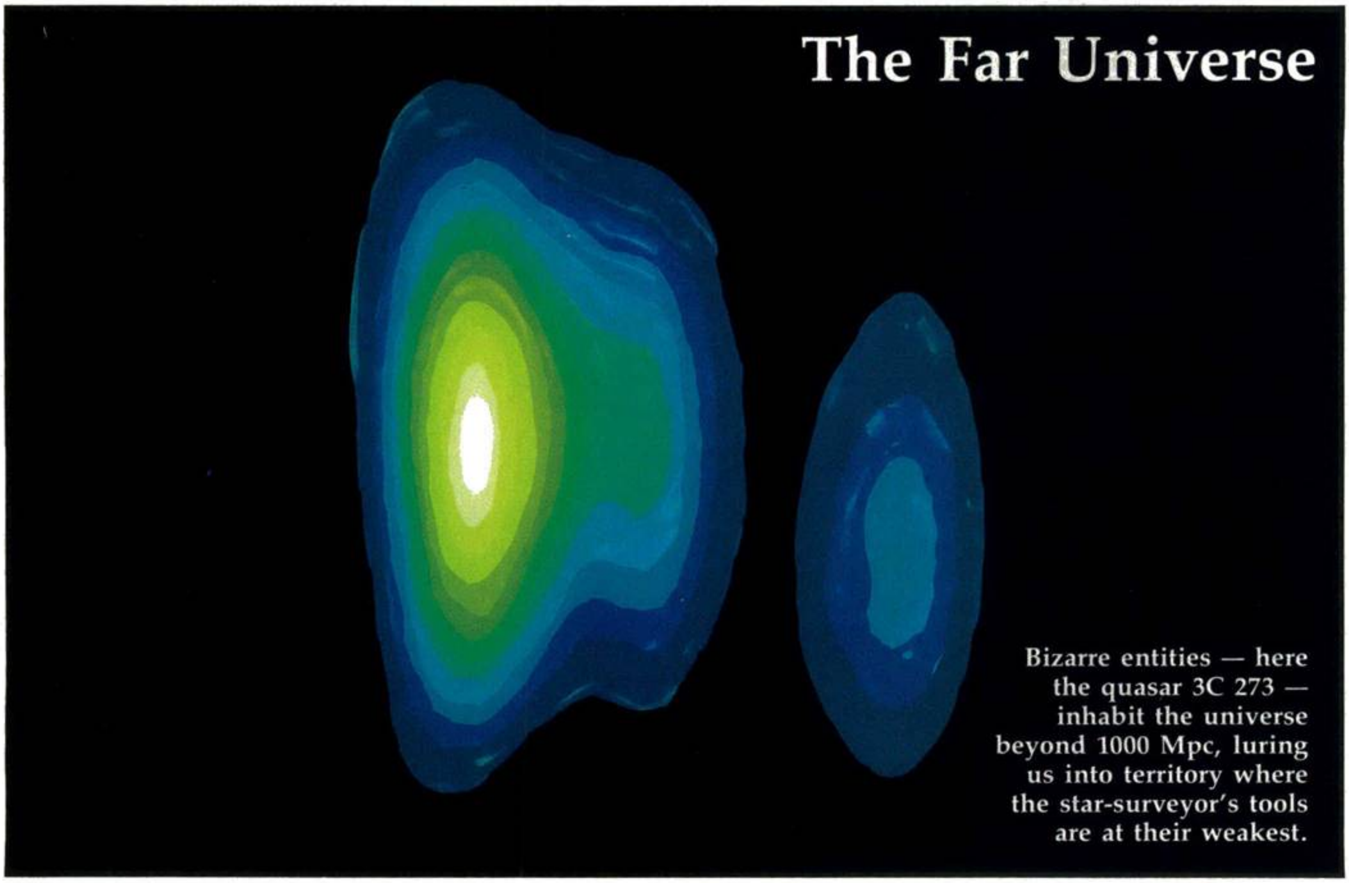
Like astronomical stepping stones, deep space surveying techniques take us from our planet's surface to the farthest reaches of the universe.

UNCERTAINTY
Uncertainty Very Small
5 - 50%
20 - 50%
10 - 50%
1000 Mpc
10 Mpc
4 Mpc
15 kpc
5 kpc
100 pc
0.001 pc
DISTANCE
Radar, Celestial Mechanics
Heliocentric Parallax
Moving Clusters
Spectroscopic Parallax
Pulsating Stars, Novae
SURVEY METHOD


25 - 50%
less than 50%
HII Regions
Supernovae,
Globular Cluster Magnitudes
Redshift
ericksen

Painting by Barbara Ericksen

The Far Universe



Bizarre entities — here the quasar 3C 273 — inhabit the universe beyond 1000 Mpc, luring us into territory where the star-surveyor's tools are at their weakest.

of the observable universe is marked by the farthest quasar, PKS 2000-330 — 3,600 Mpc, or about 12 billion light-years.

How reliable are these great distances? Again, any given redshift's probable error is thought to be less than 50 percent, but just how much so is not known. The Hubble relation has been attacked for a variety of reasons, but it is still considered reliable for normal spiral and elliptical galaxies. True, distances beyond 1,000 Mpc are nothing more than estimates, but redshift and the Hubble relation are the only tools we have at such great distances.

Astronomers have built an enormous framework for surveying the universe, and the strength of each new method critically depends on the strength of the supporting techniques directly beneath it. These structural supports in turn depend on the validity of assumptions made at each level. And the validity of these assumptions are a test of how well we understand what we observe. Our view of the universe changes greatly with any minor adjustments in the framework's base. Fortunately, several independent techniques allow astronomers to check their values for the nearby objects within the local universe. These cross ties help shore up the base of the framework. It is an elegant structure, but far from perfect.

In 1966 the accepted distance to the Hyades open cluster was attacked. Several astronomers showed that heliocentric parallaxes to Hyades stars were of poor quality, proper motions and radial velocities were imprecise, and the whole moving cluster method might be affected by small expansions of the clusters themselves. When things finally settle down, the accepted Hyades distance will probably be 20 percent greater than the present value — about 55 pc. Since the Hyades distance is the cornerstone of many ranging techniques, this change will affect the entire distance scale.

Distances within the Local Group may also have serious problems. Recently, some astronomers began working from scratch and re-observed many of the Cepheids Hubble found in M-33. The new results indicate that M-33 may be 50 percent farther away than astronomers now believe. If this new distance is correct, M-33 is considerably larger and brighter than previously thought.

Astronomical surveying is an active field. The construction of a strong extragalactic distance scale seems to be an impossible task; perhaps for the moment it is. Now there are only uncertain methods, fragmentary data, and little understanding of the physical nature of our stellar and galactic standard candles. Astronomers might do well to stop trying altogether and concentrate on perfecting the distance scale within the Milky Way. After all, the nature of galactic evolution, modifications of stellar pulsation theory, and differences in chemical abundance may have serious effects on known indicators of distance.

But the far universe beckons. Superclusters of galaxies, the radio screams of quasars, galactic jets squirting hot gas millions of light-years — these creatures of the distant universe steal our attention from the familiar suns of home. The universe taunts us, forces us to try to establish a distance scale so that we can at least attempt to understand these new discoveries. The temptation to explore, to probe, to wonder is simply too great.

> *But I assure thee, that all these seeming Extravagancies that I must run through, are no Jests: Far from it, they must be all perform'd seriously and solemnly . . .*
>
> — Miguel de Cervantes,
> *Don Quixote*

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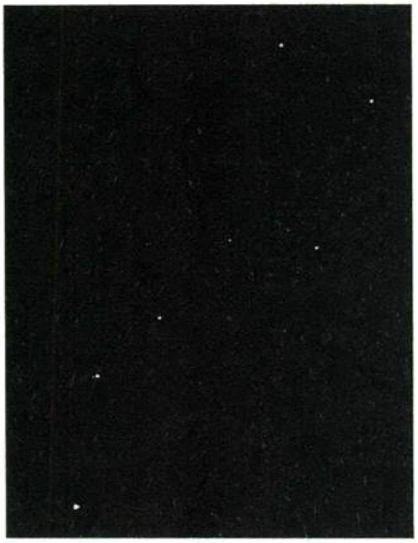
Suppose that this happens to you. You want to participate, so you buy a telescope — only to find out that you don't know how and where to look for what. And should you find the object you were looking for, you may see a faint wisp instead of the sparkling jewel you were expecting, because visual appearance through even the largest amateur instrument bears little relation to a photograph taken with a giant observatory telescope.

What you do when you start astronomy is take a running jump into the unknown — unknown because it is at the ends of the cosmic scale of dimensions, the almost infinitely small of nuclear physics and the almost infinitely large of astronomy, that ordinary experience and sound common sense totally desert you.

You will need an instrument on which you will be totally dependent. But since you are not an expert in optics, you may not have the foggiest notion of what type and quality are necessary.

This is all the more ominous, since you have no inkling of what you are going to see and what category of objects you will eventually like best — a factor that determines what sort of telescope will best suit your needs.

Finally, you realize that you really know very little astronomy, and pinpoints of light are not very interesting in themselves. You have no observing experience whatsoever, and your nocturnal exploits may so far have been limited to indoor activities . . .



No wonder, then, that a great number of telescopes today collect dust in garages and attics. They bear silent testimony to the fact that astronomy can become a complete disappointment unless you tackle it with forethought and forewarning. Yet there is a sure way to avoid such a costly disillusion. It is not a road that leads to instant dazzling expertise or immediate grand tours of the heavens. But the journey never overloads your budget, and it leads past interesting scenery and gives you the priceless treasure of experience. Your phased approach to astronomy will take two years at minimum, but at the end of your apprenticeship you will be a topnotch observer. If this is what you would like to be — and remember, there is perhaps one good observer for every dozen casual stargazers — here is how to proceed.

Phase One: the Naked Eye

Let's assume you have the astronomical knowledge of a typically well-educated person, which as we have seen amounts to practically zilch. To correct this, you will buy an introductory text and subscribe to a journal (I am not going to suggest which one). Since you will be traveling through unknown country, you will also need a good map. Buy the best you can afford; I recommend *Sky Atlas 2000.0* (Tirion) because it is very detailed and large enough to remain useful in later stages.

Next, go out and learn the constellations. The program described in ASTRONOMY ("Learning the Constellations," ASTRONOMY, December 1977, and April, July, and October 1978) will keep you fully occupied for a year, since, of course, that's not all you can do.

Regular observing will also give you an idea of celestial mechanics. It is quite confusing at first — you will appreciate why it took humanity thousands of years to work it out! When does the Moon rise in relation to its phases? How does it move through the sky in the course of a week, or a year? Watch how the stars are shifted as your Earth orbits around the Sun; observe how different constellations become visible every season.

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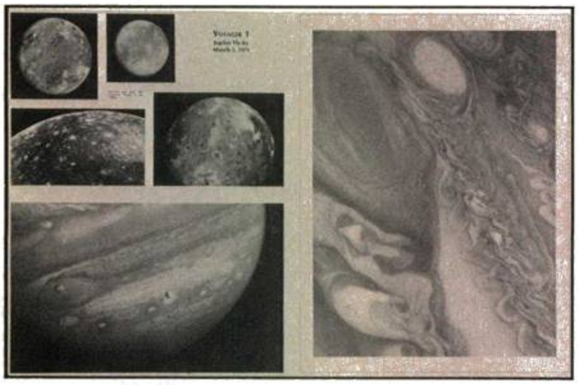
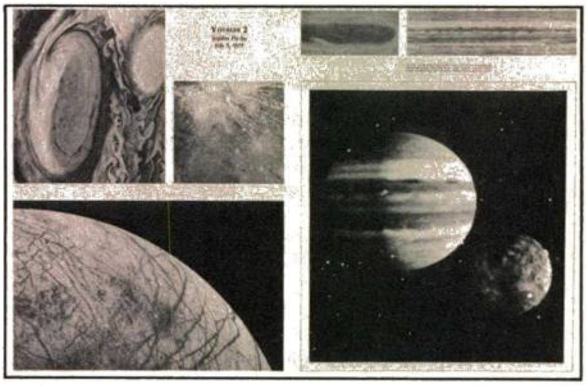
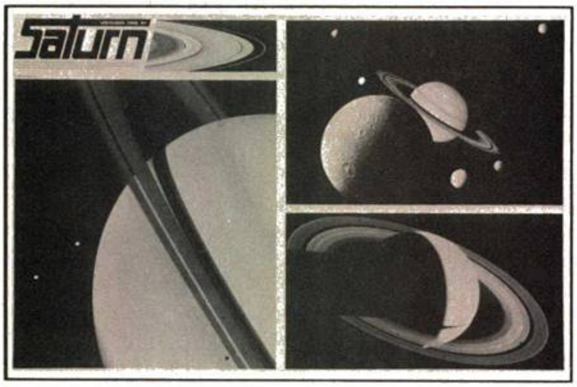
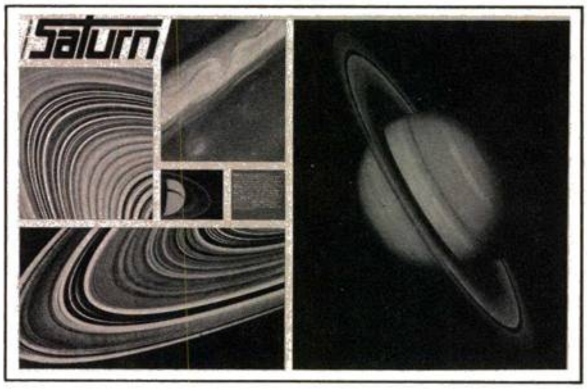
JUPITER 1. Images from Voyager 1 of the Red Spot, floating satellites against the planet and close-ups of the fabulous Galilean moons.

JUPITER 2. Six more unduplicated photos of the miniature solar system from Voyager 2. A perfect complement to the Voyager poster at left.









SATURN 1. The jewel of the solar system reveals its hundreds of rings, radial spokes and curious collection of satellites.

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After some time, you will begin to have an idea of whether a certain star is visible or not this month, or if it will become visible next week. Also, you can get used to celestial coordinates, acquiring a feel for the great invisible gridwork in the sky and how the altitude and azimuth of a star changes as it rises.

For watching sunspots, use dark welders' goggles. Watch for a rare phenomenon at sunset called the "green flash," which few people have ever seen. Try to spot the faint zodiacal light in February and March after sunset or September and October before dawn — though you'll need very clear and moonless skies. Even more difficult to see is the "gegenschein"; look for it in the direction exactly opposite the Sun. Although it is a quite unspectacular faint glow, remember that you are actually looking at interstellar matter!

If you don't live too far south, you may see the aurora borealis. One of my first memories (around the age of three) is when my father woke me in the middle of the night to show me the northern lights. Perhaps you can start bridging the generation gap now by doing just that!

You will notice the naked-eye planets, and as you study the sky to learn the constellations, you'll see artificial satellites pass silently overhead. For Mercury, you may have to wait another year. Many small "shooting stars" will be visible, and if you're lucky, you may see some exceptional phenomena.

On August 2, 1975, I had just noted that no stars were visible yet, when I saw (to quote my observing diary): "a giant meteor, very long trajectory, bluish flame with fragments breaking off, leaving an orange-tinted trail visible for several minutes." Such a fireball or bolide is a rare and impressive sight, an exceptional observation you cannot demonstrate to anybody. I have never seen another — except for the very next day — and I will forgive anybody who thinks this is at the outer limit of credibility.

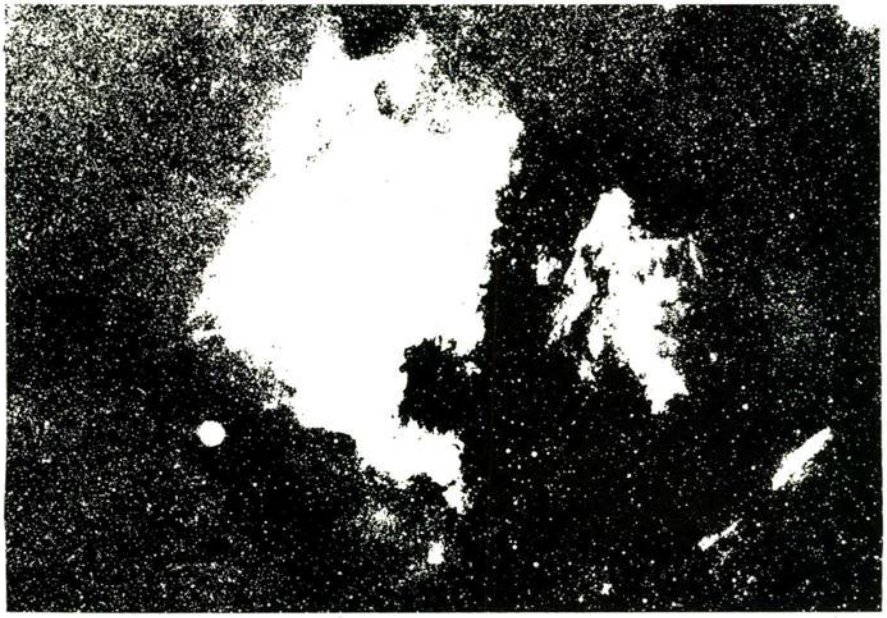
A telescope would have been useless, by the way.

In the process of getting to know the constellations really well, other exceptional observations may await you. Any amateur astronomer can point out the constellations Cassiopeia or Aquila. But ask them for Scutum Sobieski, and only a few will know where to find it. Yet this inconspicuous constellation harbors a variable star that blinks on and off: R Scuti varies irregularly between magnitudes 9.0 (invisible to the naked eye) and 4.5 every 144 days or so.

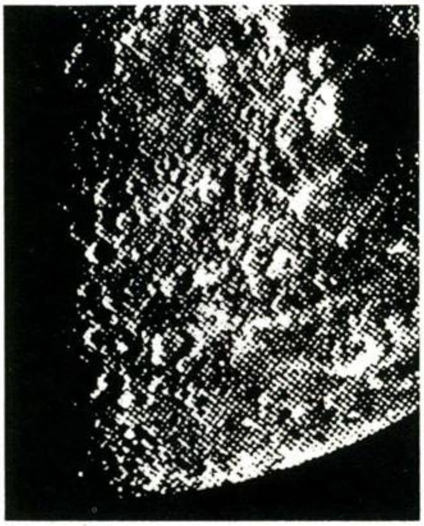
Another well-known variable star is Mira, or Omicron Ceti, which takes about a year for a complete cycle. Whenever Corona Borealis is visible, you should look for the recurrent nova T Coronae Borealis. Normally it is invisible to the naked eye (at 11th magnitude), but in 1866 and 1946 it erupted to magnitude 2.0 — nearly 4,000 times brighter. If and when this will happen again cannot be predicted.

The whole point of Phase One is to realize that *observation* is what counts, not what equipment you use. And you will gain observing experience. You will have an idea of the number of nights suitable for observing and of the rigors involved such as cold, dampness, wind, and midges. You may have found a few precious spots in your neighborhood where foliage blocks stray light from street lamps.

By noting the magnitudes of stars you can see, you have also begun to learn how to estimate brightness and have gained an idea of how light pollution and haze affect it. In addition, your eyes will be trained to look at dim objects.



Another thing you've learned is how to use star charts. Don't take your star atlas outside. Instead, lightly trace the relevant portions of the sky from the atlas (photocopying is easier, but tracing helps you to memorize what you are going to see), then fill in the star dots with a felt-tipped pen. Keep your "finder charts" in plastic covers for use outside, and add notes as you use them. Since you must use faint red light so you don't spoil your night vision, make your notes in green ink — this gives the highest contrast.

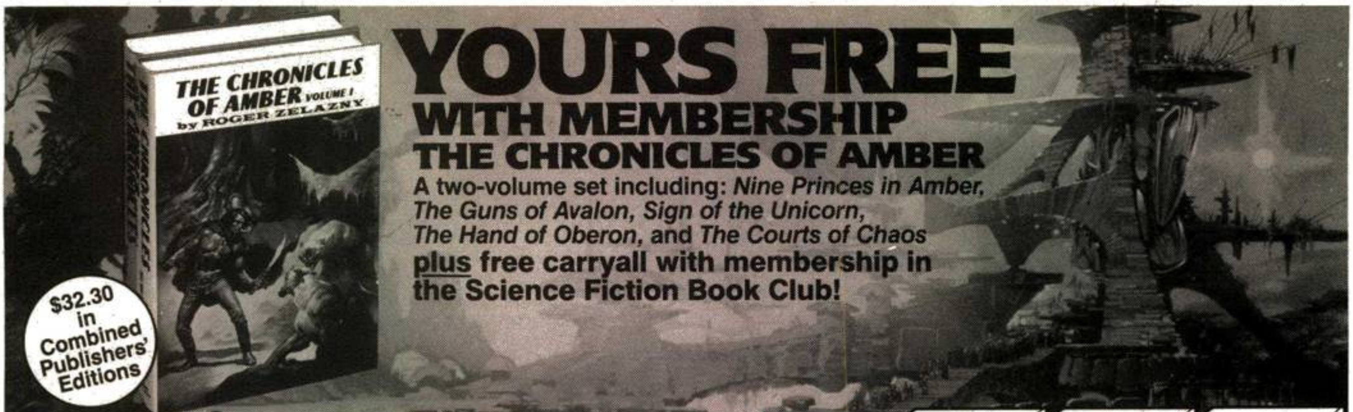


Finally, you will know how much you can combine frequent observing with your family life and profession. You are now ready to buy an optical instrument.

Phase Two: Optical Aid

And here is where I am going to suggest a totally different procedure: do *not* buy a telescope yet! Even a small telescope will suddenly show 60,000 stars instead of the 3,000 visible to the unaided eye, and even the lowest magnification makes orientation in the sky difficult.

Whatever telescope you eventually plan to have, however, will need a finder scope — but those normally supplied are hardly ideal. First, the scope must have a right-angle prism, because "straight through" viewing of objects overhead (where they are best visible) is very uncomfortable. Second, an objective 30mm in diameter, as normally supplied, is on the small side for finding dim objects. One 50mm in diameter would be better. You should, therefore, buy the best 7 x 50 right-angle finder with a wide field of view (say 5°) that you can get. For two decades I have used a finder that came with a 90mm field gun during the Second World War — an excellent piece of equipment, though now scarce. If you mount your finder on a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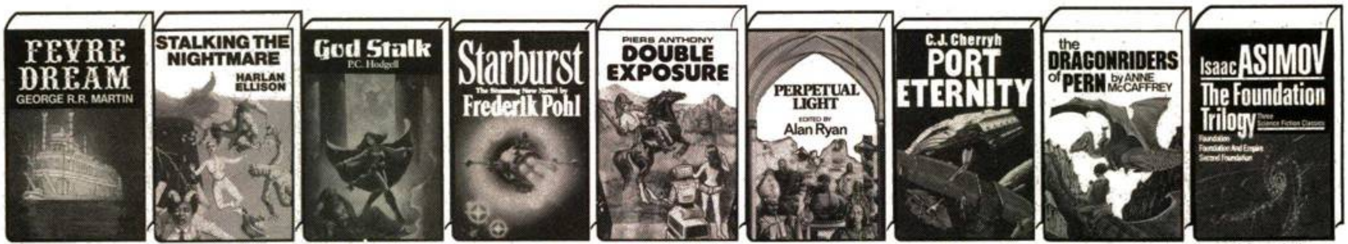
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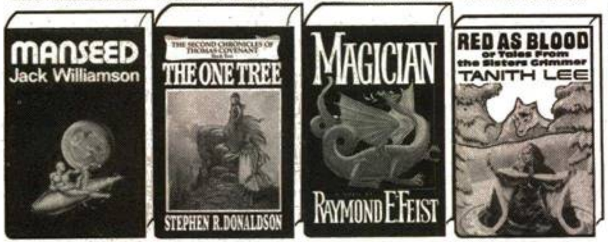
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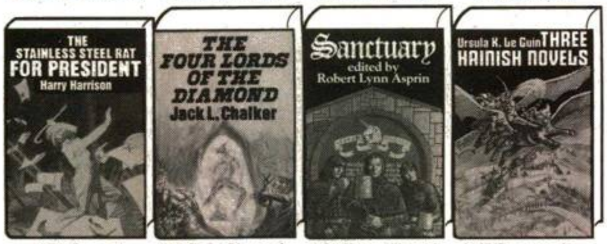
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heavy photographic tripod or home-built stand, your viewing will be more comfortable.

How will you recognize a good finder? If you always wear glasses, look for a finder with good eye relief — it will save you from a great deal of blasphemy since you can keep your glasses on while looking through it and not sit on them in the dark! Its focusing must be smooth and precise, without play or wobble. And although you are no expert in optics, you can test the optical quality to some extent. This is best done on actual stars at night, but a brick wall about 100 yards distant is also a suitable test object.

Incidentally, one thing to consider is the diameter of the eyepiece barrel — if the objective lens is of good quality, you can use short-focus eyepieces for higher magnification. The standard diameter barrel, in which there is a wide choice of eyepieces, is 1¼".

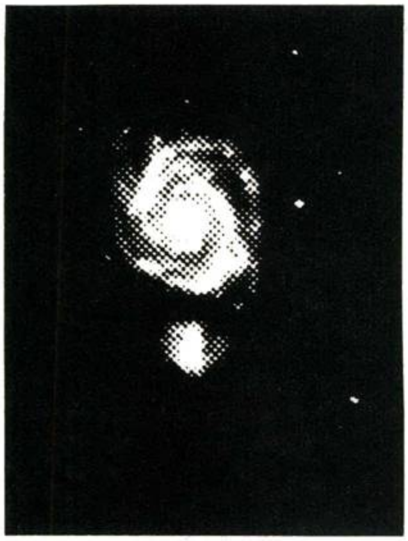
You now have a splendid "rich field" telescope at 7 power and a small telescope at about 20 power, which is sufficient to show the rings of Saturn and many details on the Moon, for instance. The possibilities now open to you are really tremendous. A huge number of stars, doubles, clusters, and nebulae now become visible — far too many to know by heart. Even your *Sky Atlas* shows only a small fraction of the number you can see! At this point you might expand your library with, say, a good college astronomy text, a book dealing specifically with binocular stargazing (your finder is comparable), and Burnham's excellent *Celestial Handbook*. Complete your *Sky Atlas 2000.0* with the *Sky Catalog 2000.0* — at first it will seem like nothing more than an enormous collection of numbers, but it is astonishing what they can tell you.

Exploration of the constellations now becomes a big project. But you can do much more with your "super-finder" — and I am going to suggest two projects that will keep you occupied for months and months.

The first is to acquire an equatorial mount. Ideally, it should be quite oversize so that it will carry your super-finder now and a good-size telescope, perhaps an 8-inch Newtonian, later on. You can construct a simple mounting yourself, as shown, for example, in *Telescope Making* magazine; or buy a large, heavy-duty commercial mount.

You can acquire experience by practicing polar alignment; observation becomes much more convenient, and you can now search for objects by "star-hopping," even without right ascension and declination scales. You should first determine the field of view of your finder scope for the magnifications available by measuring the angular distance between the stars of approximately equal right ascension or declination on your atlas and comparing this with the field of view. Using this value for your angular field of view, you can start from an easily identifiable star and estimate the position of a more difficult object fairly accurately, as indicated in the chart. This is excellent preparation for work with your future large telescope.

The second project may come as a surprise: you can make a start in astrophotography. If you have a stable equatorial mount, you can piggyback a camera on the finder, using it as a guidescope. If the finder is used at its highest magnification, say 20x, and guiding done carefully by hand, the errors will still be acceptable — even if the camera has a lens longer than 50mm focal length and your exposures run longer than just a few minutes. For a start, however, your 35mm camera's "normal" lens is perfect for star photography. Ideally, you'll equip the finder with an illuminated crosshair eyepiece — an eyepiece which you will later use with your telescope when you eventually wish to make astrophotographs of high quality.



A fascinating program to undertake, once you can take photographs that turn out well on a regular basis, is to make your own photographic atlas of as much of the sky as you can. You will be amazed. If you thought your *Sky Atlas* shows a lot of stars — the photographs put it to shame!

If possible, each photograph should be taken twice with a rather long interval (a week or so) between exposures. If you take care to use the same film, same exposure time, same duration and temperature of development, and take the photographs when the objects are culminating (reaching their maximum height above the horizon), you will build a collection of very valuable material.

Merely identifying the uncountable objects becomes a task of gigantic proportions, but the photographs may also be used to detect variables, asteroids, and possibly comets and novae.

Phase Three: Possibilities Unlimited

Should you have decided somewhere along the road that astronomical observing is somehow not feasible for you, at least it will have occurred before you invested in an expensive mount. Since you may use the finder for terrestrial observing and an occasional glance at the sky, there is no financial loss involved. If you have retained your interest in astronomy, however, you are now much better informed.

You have a very good idea of what can be seen from your location, and perhaps a certain class of objects or certain activity has gained particular interest for you. Suppose your aims are high: you decide on deep-sky astrophotography. What you might do first is buy a good 60mm or 75mm refractor and combine this with your finder, Barlow, and oversized mounting. Depending on the quality of the mounting, you can then piggyback a camera with a telephoto lens or even a Schmidt camera. The secret is that, more than anything else, deep-sky astrophotography requires a good guidescope, and your 60 mm or bigger refractor is just that. Your special eyepiece for guiding is now a worthwhile investment. And if you really are going to go all the way, you may build or buy a fast (f/5 or so) 8-inch Newtonian, combine this with your excellent finder and guidescope on your very stable mounting with motor drive — and enjoy the vast possibilities available.

By the time you reach this stage, you will have been involved in astronomy for perhaps three years. You have avoided the danger of developing a superficial — and therefore passing — interest. You started with the firm foundation of stars and constellations, rather than the rather small number of really spectacular objects visible each night, so the vast number of less spectacular objects never became an anti-climax.

But the most important advantage to the phased approach to astronomy is that you constantly build your knowledge and experience — and this road to the stars requires only occasional investments in top-quality equipment that you'll continue to use for years and years!

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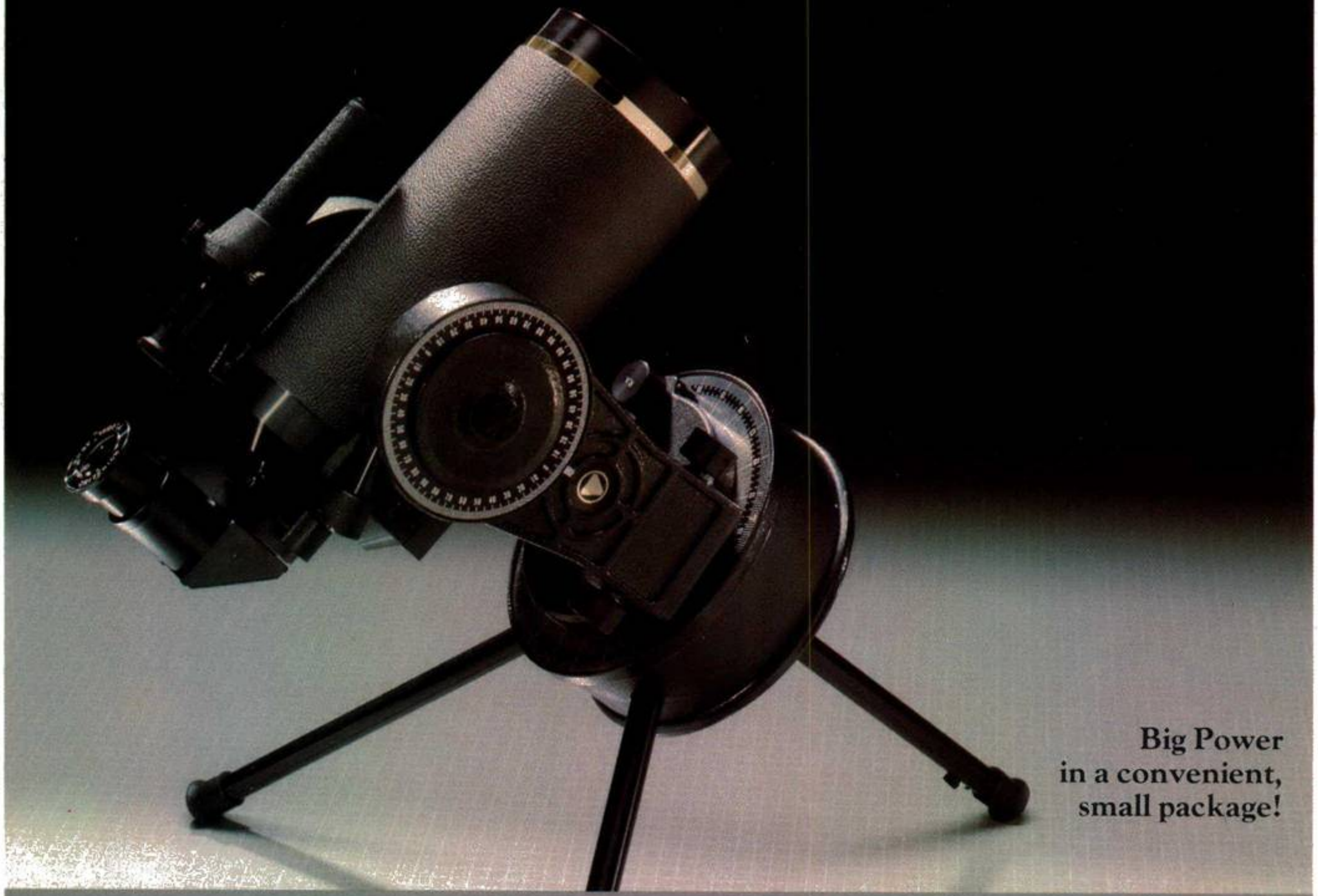

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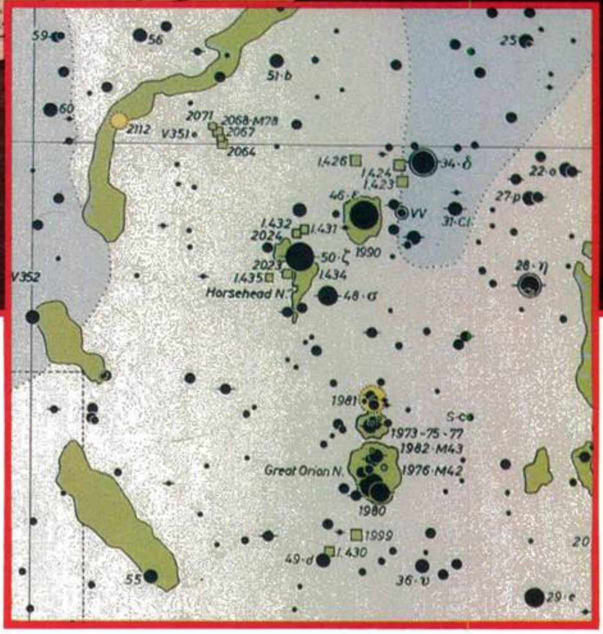
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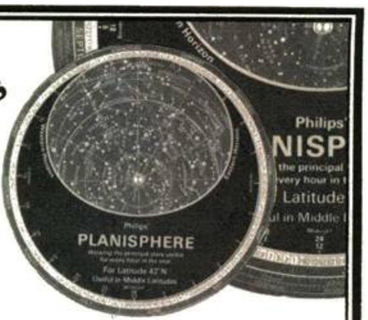

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ASTRONOMY
IN FOCUS

The Colors in M-42

Sir / After reading "Are You Ready?" (Behind the Scenes, March), I was a bit bewildered by your comments regarding visual observations of colors in M-42. I can't seem to shake the uneasy feeling that these comments were directed toward "Exploring the Nebulosities in Orion" (Gazer's Gazette, December 1982). In that article, I described the rusty-red fringes of the Great Nebula as seen in my 8-inch reflector. The phenomenon, though visible only on the best of nights, was nevertheless confirmed time and time again by at least a half dozen experienced observers in our party.

Do we all have "overactive imaginations"? I would hope that 15 years of deep-sky studies have given me a somewhat scientific, honest approach to my observing. As you well know, many variables come into play when observing deep-sky objects, not the least of which is the sensitivity of the observer's eyes to faint color.

Gary W. Keltner
Englewood, CO

— What most people imagine when they hear "the colors in M-42," and what you and I, based on our observing experience, mean when we say "the colors in M-42" are two very different things. I have found that too many people expect to see color — vivid neon sign color — when they look through the eyepiece.

So, as an editor writing for a vast and mixed readership ranging from wet-behind-the-ears equipment freaks to dyed-in-the-wool observers, I wrote, ". . . only faint and hard-to-see grey-reds and grey-blues . . ." — words chosen to communicate exactly what I have seen, without any observer's jargon. I think "no color at all" is a fair description of the way the Orion Nebula is seen in a small telescope by the average newcomer to astronomy.

But speaking observer-to-observer, if I were to say that I have seen "bright red and blue streamers extending south and west, pearly whitish-pink coloration in the central mass, with a 20-inch reflector," you would know exactly what I mean by those words. Most people wouldn't.

I am sorry that I seem to have stepped on your toes. That was not my intention. Your description of the colors is thoroughly honest and accurate: ". . . under ideal skies, you may see some reddish or rusty coloring in its outer fringes. . . ." I certainly do not dispute what you have seen or the way in which you described it.

Thanks to Fulton

Sir / Ken Fulton's article lifted my spirits and renewed my sense of determination. I'm a 67-year-old retiree, and I've had numerous "hard knocks" in life — some my own fault and some unexpected. However, I have survived them. Now, as a novice in amateur astronomy, I expect some more "knocks," and I'm quite sure I'll survive.

Although southern Michigan is not exactly an astronomer's paradise, especially the Detroit area, I don't intend to give up. I have had a dose of the celestial wonders — and somehow the awe has never left me. Stargazing gives me a sense of peace and tranquility, though I am fully aware of the evolutionary drama being enacted in the heavens.

Thank you for a frank and honest article.

Fred Seabow
Taylor, MI

Zap! — You're There

Sir / I conjured up a little problem for our local group of amateur astronomers.

Which one of these solar system visits would you choose:

a) 1/60 second at the "surface" of the Sun
b) 1 second on the surface of Venus
c) 1 minute on a solid part of Titan's surface
d) 1 hour in central Antarctica
e) 1 weekend (60 hours) in Philadelphia

We assume the traveler is whisked instantaneously to the destination with a few seconds notice, in ordinary March street clothes, and without food or water, and is whisked home instantaneously after the visit.

We all agree that the minute on Titan would be most fascinating and instructive. However, we cannot agree on which visit would leave the traveler least damaged. In fact, each of the five destinations had its advocates as the "safest." Does the ASTRONOMY readership have a preference?

John Newmeyer
San Francisco, CA

Focus on "Chaos"

Sir / Several nights ago, my husband and I had the marvelous opportunity to read the article "From Chaos to Consciousness" (February 1983). I couldn't sit still until I had banged out my praises on the typewriter. For Don, my husband, with his degree in chemistry, the technical parts of the article were understandable and fascinating. But he had to guide me step by step through the more complicated topics of atomic fission and neutrinos. Your conclusion, however, did not have to be explained to either of us. We kept getting "ah-ha's" from page 18 to the end of the article. Subsequent to reading the article, we spent the next four hours, until two o'clock in the morning, discussing its logic, simplicity, beauty, and its ramifications. Needless to say, we loved it and plan to reread it several times! I tend to read the lighter articles in ASTRONOMY and leave the complex material to Don. But in this case, I somehow found myself nose-deep in "From Chaos . . ." before I realized that this was no ordinary "light" subject. By then I couldn't extricate myself.

Thank you for presenting your side of the physics of creation. You have revived our faith in the belief that some scientists cannot go to the brink of the world of sub-atomic particles without sensing that that world is orderly and controlled.

Gail Depue
Cambria, CA

Sir / Your article "From Chaos to Consciousness" was a joy to read — in fact I read it several times. I'm an astronomy enthusiast, and the article gave me a whole new outlook on where this universe came from.

I hope in the future there will be an update of these theories. I certainly will look forward to it.

M. Hartounin
Los Angeles, CA

The "Can't Wait" Mentality

Sir / I very much enjoyed your March editorial, "Are You Ready?" It teamed very nicely with the fine Forum by Ken Fulton. I felt that you handled well the problem of people who develop negative attitudes about amateur astronomy. It did, however, prompt me to write and give you my two cents' worth on the subject.

I received my first telescope — a humble 60mm refractor — at age 11. Although I found enjoyment (and persevered), I really didn't appreciate its potential until later, after I had used larger scopes. It was then and only then that I began "seeing" more in the small one. Perhaps the lesson is that beginners should put off buying a telescope until they have had the opportunity to use one under the guidance of another amateur astronomer with experience. It seems to me that it takes somewhat more skill to use a small aperture successfully.

After 25 years in amateur astronomy (and enjoying it more than ever), I have observed through every type of scope, including an observatory refractor; I would tend to agree that the manufacturers of scopes available to the amateur deliver a fine product. I believe that today's scopes are better than at any time in history — and more usable. I am perplexed whenever I read AstroMart and find telescopes for sale that are one year old and have been used only twice.

Is it possible that we have become a society that can't wait to acquire skills through patient growth? Or are these simply the same people who buy a musical instrument and then "get rid of it" when they can't automatically play?

Your magazine is perfectly geared to helping the amateur through his early experiences. Please *don't* change — ASTRONOMY gets better with each new issue.

Jim Stanis
Scenery Hill, PA

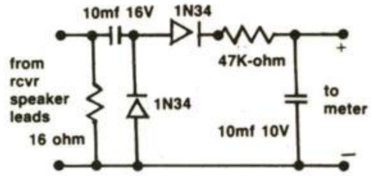
Ooops!

Robert Brown (see "Uranus' Moons Measured," AstroNews, February 1983) sends the following revised, updated diameters (in kilometers) and albedos for the five uranian satellites:

Ariel	1330 ± 130	30% ± 6%
Umbriel	1110 ± 100	19% ± 4%
Titania	1600 ± 120	23% ± 4%
Oberon	1630 ± 140	18% ± 4%
Miranda	500	assumed to be 30%

Miranda's diameter was listed as 1530 km, rather than the 530 km figure released by the researchers.

In our story on backyard radio astronomy in the March issue, we inadvertently omitted dot connections on the schematic diagram of an integrator circuit. The corrected diagram, showing proper connections between all components, appears here.



behind the scenes | the silicon revolution

Like it or not, computers are rapidly becoming a part of American life. Look at your own life. Chances are that even if you're not using a computer at work, you have one at home for learning something about programming or you're into video games. One way or another, the "silicon revolution" has touched your life.

Here at ASTRONOMY, we write and edit articles on computers, set ASTRONOMY's type with a computer, and keep corporate records with computers. Our printer uses computer-controlled printing presses. Our paychecks are figured by a computer. Your subscription record is maintained on a computer. And more and more, I've been getting letters from readers asking about home computers.

Now — how do computers tie into astronomy? Well, if you don't have one, they don't. Astronomy is the same as it has always been, you and your telescope peacefully gazing at the stars. Or so it seems. But the predictions you rely on come from *The Astronomical Almanac*, and someone ran them on a big computer several years earlier. And much of what you know about the universe, many things that you've read about in ASTRONOMY have come through the computers astronomers use to collect and analyze raw data, make mathematical models, or construct images from radio, X-ray, or spacecraft signals.

What are those readers with computers asking about? "How can I apply my home computer to my astronomical interest?" is the common theme. It's logical, too: astronomy is by its very nature predictable. Planets orbit the Sun, satellites orbit the planets, the Earth spins. You can calculate what's up when. Even a fairly small computer can handle the number-crunching involved in predicting the positions of planets and satellites in their orbits. Who needs the almanac — I'll compute it myself!

And the applications beyond almanac-ing seem plentiful. You could experiment with the orbits of double stars, watch the disruptions of colliding galaxies, or let the computer handle the tiresome math of reducing your last batch of photoelectric measurements. There are so many things you could do. . . .

But somebody has to write the programs.

And the program writers are you readers. You know who you are — you've written a dandy little program to find altitudes and azimuths with your Timex, an orbit simulation for your Apple, or something neat that we've never thought of. Drop us a letter plus a listing to let us know what you've done. If there's enough interest, we'll publish the most interesting programs for you from time to time.

Sincerely,

Richard Berry

Richard Berry
Editor

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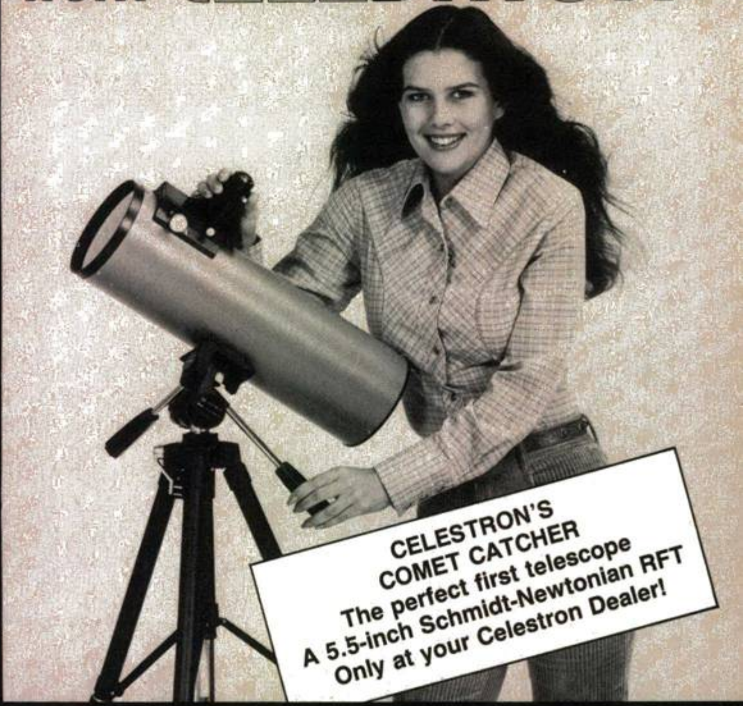

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waiting for halley

Halley's Comet is in the news again. We've all heard reports about the recovery photo taken back in October on Palomar Mountain. We have seen bits and pieces in newspapers, magazines, and even on network TV. Astronomers and the general public are excited, but it's all been just talk. Even though the fuzzy object was "imaged" using the Hale 5-meter telescope, it is still glowing at only 24th magnitude — far out of reach of most astronomical equipment for professionals and amateurs alike.

Although nothing can yet be done about observing Halley, it's a good time to start *thinking* about observing the comet. When David Jewett and Edward Danielson found Halley, the clock started ticking: it is now less than three years and counting until it will be visible in backyard scopes. And those years will pass more quickly than you might think.

What will the famed comet look like? Unfortunately, it will not be as spectacular as it was in 1910 and will probably disappoint the general public. Based on preliminary calculations, Halley will be a fourth-magnitude object at perihelion on February 9, 1986 — and then will be hidden in the solar glare. At its brightest apparition, occurring in mid-January or late March 1986, Halley will be just faintly visible to the naked eye. Of course, comets tend to be unpredictable, so an unexpected situation could arise.

But take heart. Halley may well be a barely visible letdown to the layman, but you will be able to see it quite well in your backyard telescope. The comet should brighten to fourth magnitude, and it will pass a number of interesting objects as it traverses the sky in a giant loop, beginning in Orion and ending in Sextans.

Backyard observers should first be able to see Halley about mid-September 1985, when it will be a 13th magnitude fuzzy blob near the bright star Eta (η) Orionis. It will then be about equidistant from the Sun and from Earth — still 2.5 astronomical units away. The constellation Orion will rise after midnight during this period, so if you have a big telescope — a 12-inch to a 20-inch — you'll be able to go out in the early morning and try to "discover" Halley for yourself. The best time is probably around the 14th, when the Moon will be out of the way. Plot the current position from the table on the following page on a star atlas, plop in a low-power eyepiece, and look for what may resemble a tiny faint galaxy near the estimated position. If you think you've found it, make a sketch at the eyepiece and go back on successive nights, following Halley's motion across the heavens.

Throughout October the comet will brighten considerably, bringing it within reach of most amateur telescopes. Halley will still lie relatively far away from the Sun, but it will be close to one astronomical unit from Earth. On the 18th the comet will glow at 10th magnitude and move into Taurus, heading straight for the Pleiades cluster. It should then be visible even in small telescopes: what will be the earliest date that you can pick up the comet in your telescope? On October 28 Halley should make a fine wide-field sight as it passes close to M-1, the Crab Nebula, but there will be a Full Moon in the sky. By this time it should have a total magnitude of almost 9, and it may be bright enough to start showing some detail. Look at the comet critically, and use averted vision — glancing from side to side — to obtain a better view of the comet's faint gas and dust.

In November 1985, Comet Halley will really begin to brighten; it will shine at around eighth magnitude on the 7th, when a Last Quarter Moon shouldn't hamper early morning observations. During this month, you'll have the greatest number of so-called "dark hours" — useful observing hours between the end of evening twilight and the beginning of morning twilight — so make the most of them, and see what you can during this period. In mid-November Halley will brighten to seventh magnitude and will pass just under M-45, the giant Pleiades

Hale Observatories photograph

observing halley's comet

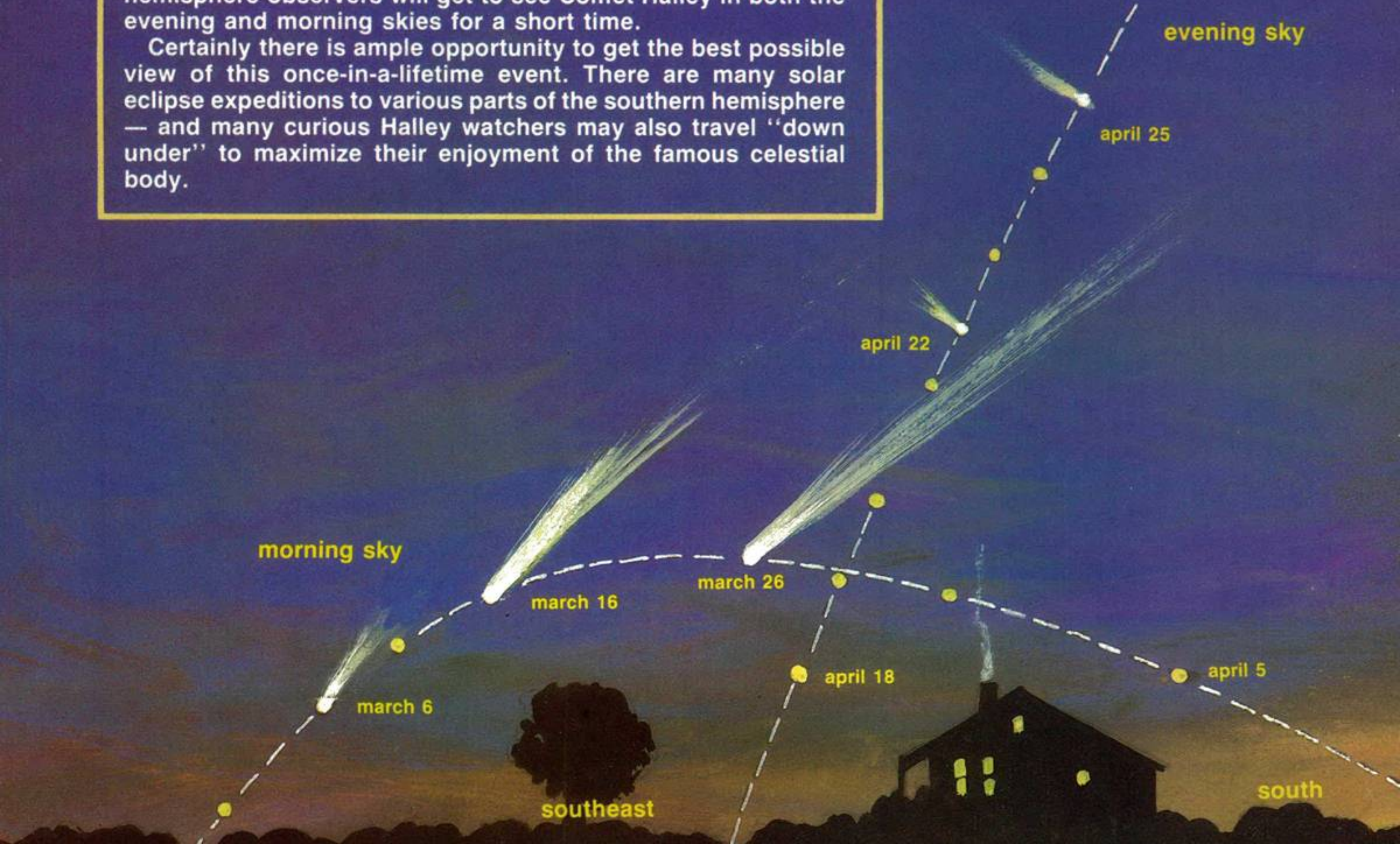
Based on the orbital elements known by astronomers, Halley's Comet should become visible in amateur telescopes in mid-September 1985. But it won't come close to being spectacular until early January 1986, when it will be a fifth-magnitude evening object in the constellation Aquarius. Two additional apparitions — both about fifth magnitude — should provide ample opportunity to view Halley: an early morning show in March, when the comet will be in Sagittarius, and an evening appearance in April, when Halley will reside in the constellation Centaurus. Artwork by Barbara Ericksen, based on JPL data.

the view from down under

Part of the problem in observing Halley from northern latitudes is that it will be so low in the sky. Atmospheric turbulence or haze, light pollution, or clouds will probably disturb our view of the legendary comet. For an observer at 40° north latitude, the highest elevation of the comet will be only 30°. Southern hemisphere observers will have a much better look at Halley since it will be high in their sky, where the view is least disturbed by the atmosphere and the sky is darkest when the comet is brightest.

For an observer at 30° south latitude early in March 1986, the comet is 30° over the horizon in the morning sky; it will make an enormous upward loop during the next one and a half months. Late in March the comet will hang some 70° high in the sky — approaching straight up at the zenith — a fantastic sight for large-telescope viewers. Toward the beginning of April, Halley reaches its highest elevation at about 80° and moves toward the southwestern morning sky. During mid- and late-April, southern hemisphere observers will get to see Comet Halley in both the evening and morning skies for a short time.

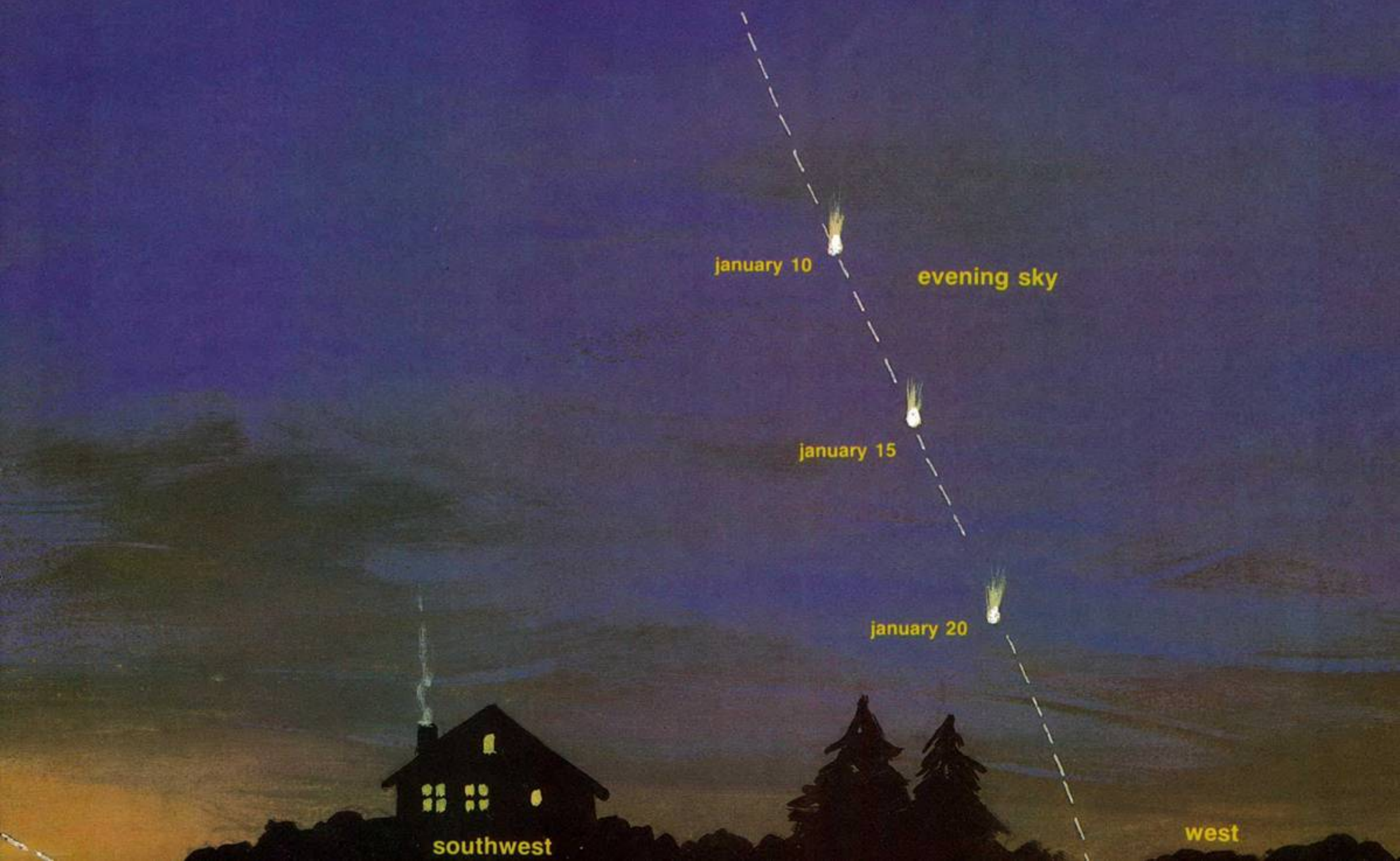
Certainly there is ample opportunity to get the best possible view of this once-in-a-lifetime event. There are many solar eclipse expeditions to various parts of the southern hemisphere — and many curious Halley watchers may also travel "down under" to maximize their enjoyment of the famous celestial body.

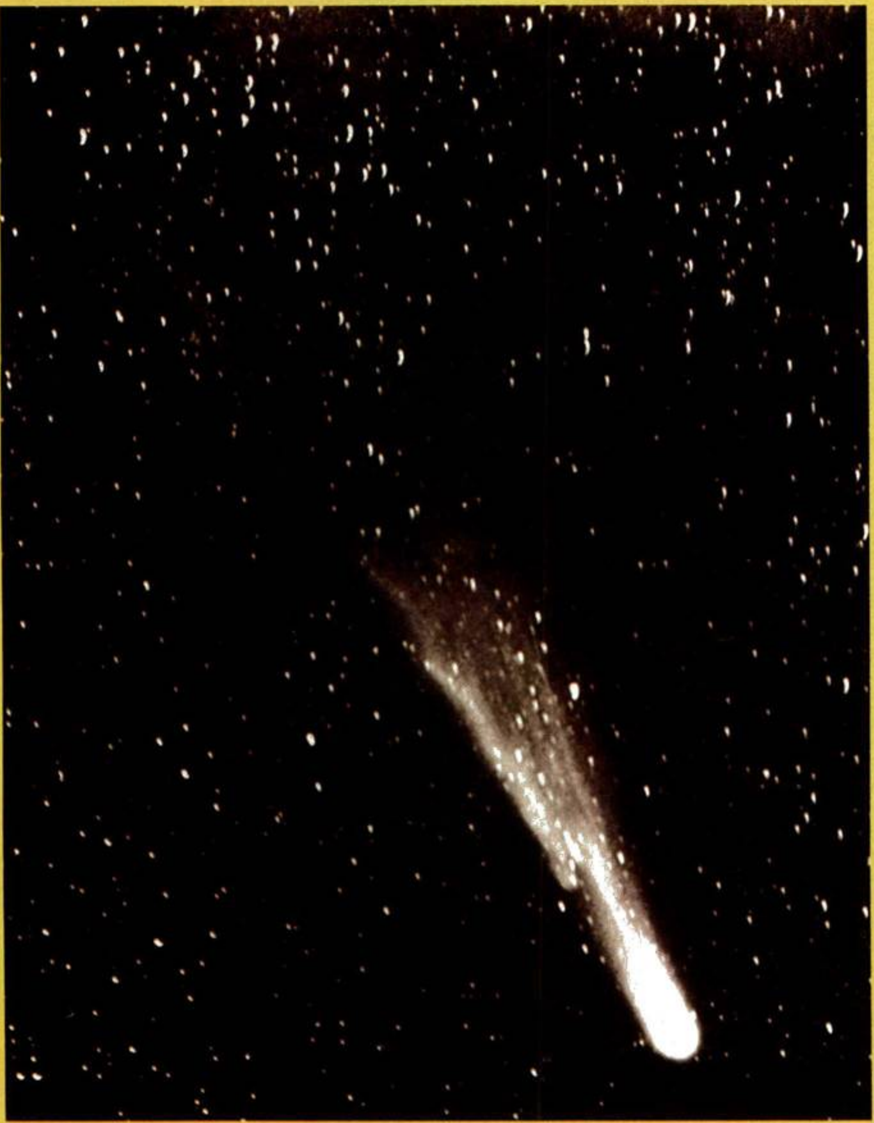


a halley ephemeris

			Hours of Darkness								
Date	R.A. (1950)	Dec.	45°N	30°N	30°S	45°S	Mv	Mc	⊙	⊕	Moon
Sept. 8 1985	06h 11m	+19°28′	4.1	4.0	2.9	2.2	12.7	13.9	2.6	2.8	LQ
Sept. 18	06h 13m	+19°39′	5.0	4.8	3.3	2.5	12.2	13.5	2.5	2.5	NM/FQ
Sept. 28	06h 12m	+19°54′	5.9	5.6	3.8	2.8	11.6	12.9	2.4	2.1	FM
Oct. 8	06h 08m	+20°16′	6.9	6.4	4.3	3.1	10.9	12.3	2.3	1.8	LQ
Oct. 18	05h 57m	+20°47′	8.0	7.3	4.9	3.5	10.1	11.6	2.1	1.5	FQ
Oct. 28	05h 36m	+21°29′	9.2	8.5	5.7	4.1	9.3	10.8	2.0	1.2	FM
Nov. 7	04h 55m	+22°09′	10.7	10.0	6.8	5.0	8.3	10.0	1.8	0.9	LQ
Nov. 17	03h 40m	+21°34′	11.1	10.6	7.3	4.9	7.2	9.0	1.7	0.7	FQ
Nov. 27	01h 51m	+16°51′	10.6	9.8	7.0	4.2	6.4	8.4	1.6	0.6	FM
Dec. 7	00h 11m	+08°54′	7.7	7.1	4.4	3.6	6.1	8.1	1.4	0.7	LQ
Dec. 17	23h 07m	+02°41′	5.5	5.1	2.8	1.0	5.9	8.1	1.2	0.9	FQ
Dec. 27	22h 29m	−01°08′	3.9	3.6	1.5	0.0	5.6	8.0	1.0	1.0	FM
Jan. 6 1986	22h 05m	−03°37′	2.6	2.3	0.5	0.0	5.4	7.7	0.9	1.3	LQ/NM
Jan. 16	21h 46m	−05°30′	1.3	1.1	0.0	0.0	5.1	7.2	0.8	1.4	FM
Feb. 9	21h 03m	−10°21′	perihelion: invisible				4.1	6.2	0.6	1.6	NM
Mar. 7	20h 17m	−18°31′	0.2	0.9	2.0	2.0	4.5	6.8	0.8	1.1	LQ/NM
Mar. 17	19h 54m	−23°41′	0.5	1.5	3.3	3.7	4.5	7.0	0.9	0.9	FQ
Mar. 27	19h 09m	−32°16′	0.7	2.3	5.3	6.2	4.3	6.9	1.1	0.7	FM
Apr. 6	17h 03m	−45°19′	0.0	3.8	9.1	9.4	4.0	6.7	1.3	0.5	LQ
Apr. 16	13h 03m	−40°30′	6.0	8.3	10.0	9.9	4.6	7.2	1.4	0.5	FQ
Apr. 26	11h 17m	−23°42′	6.2	8.0	9.2	10.0	5.4	8.5	1.6	0.7	FM
May 6	10h 42m	−14°38′	5.5	5.1	7.7	8.3	6.5	9.7	1.7	1.0	NM

The first three columns list dates and coordinates for viewing Halley. The following four columns provide the "hours of darkness" for various latitudes: these are the useful number of observing hours when the Sun is 18° or more below the horizon and when Halley is visible. The Mv column gives approximate visual magnitudes for the comet, and Mc is the approximate visual magnitude of the coma, both based on the 1910 apparition. Under ⊙ we find the distance between Halley and the Sun, and under ⊕ we get the distance between Halley and Earth, both in astronomical units. The Moon column lists the approximate phase of the moon on the dates: NM = new moon, FQ = first quarter moon, FM = full moon, and LQ = last quarter moon. Data courtesy Don Yeomans and Steve Edberg, JPL.





This photo of Comet Halley — taken on June 6, 1910 — shows the "discarded" portion of its tail drifting away from the nucleus. Yerkes Observatory photo.

star cluster. At this time Halley will be less than one astronomical unit away from us and just under two from the Sun. Toward the end of the month the comet should brighten to magnitude 6½, but a Full Moon may disturb observations. The comet is now moving fast across the sky and has reached Aries — but it still has a long way to go before it becomes invisible.

During the last month of 1985, Halley continues to swing southward and moves through the constellations Pisces and Aquarius. The useful number of dark hours will significantly decrease this month, but as the comet gets closer to perihelion and harder to observe. In the first part of December it should still be visible early in the evening, hanging over the western horizon and glowing at sixth magnitude. It should be a nice sight in binoculars and possibly even visible to the naked eye. As the month rolls on, the Moon will begin to interfere — so observe early in December.

Halley's Comet will be a fine sight just before its closest approach to the Sun. In early January 1986, as it moves to less than one astronomical unit from the Sun — and stays slightly farther away from us — it should be visible in Aquarius as a fifth-magnitude object. It may now show signs of a tail along with its bright coma; its tail will develop more after perihelion. Between the 6th and the 16th, when it will continue brightening, and so should present a nice telescopic show in the evening sky. The Moon will interfere toward mid-month, however, so keep your telescope busy during the first days of the new year.

On February 9 Comet Halley will reach perihelion, its closest approach to the Sun, at a distance of about 56 million miles from Sol. Unfortunately, it will be invisible to us at this time — lost in the solar glare. Halley will then be at its brightest — it's predicted to reach fourth magnitude — and will pass very close to the planetary nebula NGC-7009, the Saturn Nebula.

Halley becomes visible again in March — this time in the morning sky — but you'll have only a short time to watch, since the comet rises just before sunrise. By the 7th it has moved down into Capricornus and shines at fifth magnitude, now about one astronomical unit from both the Sun and Earth. During this period, the comet will grow its largest tail. It may be a pleasing naked-eye sight shortly before daybreak during the first two weeks of the month. Continuing southward, Halley passes by globular cluster M-75. On the 17th it will be located in eastern Sagittarius, still shining at magnitude 5. As the month closes and the Moon again interferes, the comet will brighten (because it moves closer to Earth) to around fourth magnitude and will rest under the "Teapot" near the strange variable star RY Sagittarii.

Rapidly moving southward, Halley will again become invisible to northern observers until it moves into the evening sky in mid-April. On April 9th — New Moon for the month — it will lie in the constellation Lupus and will shine at fourth magnitude, but will be out of sight for the Northern Hemisphere. Not until the comet moves into Centaurus will we again see its now-diminished tail and slowly dimming nucleus.

On the 15th the magnitude 4½ object, at its closest approach of 47 million miles from Earth, passes the exploding galaxy NGC-5128. Although Halley will have become fainter, you'll have much more time to observe it than you did in March. Toward the end of April, Halley moves northward and climbs slightly higher in the sky for northern observers, but its fifth-magnitude surface will be harder to view because of a Full Moon.

Halley's apparent motion will slow as it begins its journey back to the outer solar system. It will probably continue to be visible throughout May and June. During the first week of May it is still a magnitude 6½ object jumping the border from Crater into Hydra; there will be no Moon to obliterate it. Toward the end of the month the comet will drop another magnitude, but a Full Moon will prohibit good observations. And as June begins, trying to observe the icy ball of gases will become more and more difficult; the Sun will move closer to Sextans, and eventually Halley will be lost in sunset.

Comets like Halley are largely unpredictable creatures. Trying to foretell exactly what will happen is tricky, so keep your eyes open during the final months of 1985. The comet may turn out to be brighter than we think, or may be even dimmer than fourth magnitude. We can use the information on Halley from past observers, but we still must be prepared for the unexpected. All we can do for the moment is plot out the estimated orbit on a star chart, polish up our eyepieces, and keep waiting. — *David J. Eicher*

ASTRONOMY REVIEWS

Deep Sky Detail Charts
Thomas M. Sarna
102 8½"x11" charts and finder map, $30 + $2 postage
Sarna and Associates (1982)
[publisher's address: 7133 Blackburn, Downers Grove, IL 60516]

As a specialized interest in backyard astronomy, deep-sky observing is growing in popularity. This is true largely because of the increased availability of large telescopes. Over the last five years, the "Dobsonian revolution" has increased the size of backyard scopes so that an average aperture is now probably 8 or 10 inches. But this new breed of observer — one who sets off to observe faint fuzzies with a pretty large scope — faces an unusual problem: he must *find* all of those little nebulous smudges.

Locating the objects can be the most frustrating part of observing. If you use an atlas like *Sky Atlas 2000.0* or *Norton's Star Atlas* and a large finderscope, at least an 8x50mm, you'll probably do all right after some practice in star-hopping. But wouldn't it be nice to have some extra help? After all, the best star atlases easily available to amateurs have a limiting magnitude of 8.0 and a plate scale of around 8'/mm — not very detailed, when you're out observing with a 16-inch scope at 300x. Fortunately, an observer near Chicago has produced a set of very detailed finder charts for the entire Messier list and an additional 145 NGC objects.

The nicest feature of the charts is that they contain specific coordinate directions from nearby bright stars. For example, the chart showing globular cluster M-30 in Capricornus instructs the user to start at Delta (δ) Capricorni and move 6.7' west in right ascension and 7°04' south in declination. With a low-power eyepiece, M-30 should appear there in all its glory. Having a plot of the stars around deep-sky objects will surely prevent big-scope users from getting lost in a sea of apparently identical starfields.

The charts are printed on 8½" x 11" uncoated card stock, so be careful to protect them from moisture when you take them out with your scope. The dark blue ink should be easy to see with red flashlights. At first glance, the charts look almost like AAVSO variable star estimating charts, but they should not be used for magnitude comparison. Sarna used photographs to plot the stars, but they are not as accurate as AAVSO charts. They are, however, accurate enough to serve their purpose: They give the new breed of large-aperture deep-sky observer a quick, straightforward method for finding the brighter deep-sky objects.
David J. Eicher

Mission to Mars
James E. Oberg
221 pages, hardcover, $14.95
Stackpole Books (1982)

Is this really the most politic time to introduce a popular-level, yet serious, book on manned exploration and eventual exploitation of Mars? NASA has spent this past decade keeping very quiet about the various studies which have, nevertheless, continued behind closed doors. Senator Proxmire is not the only one waiting to slap a Golden Fleece on anyone or anything that offers the least hint that the taxpayers' money might be spent on such a project.

But should these people deign to read a book so clearly irrelevant to such worldly concerns as the decline in American science, they will find surprisingly little ammunition here. Based largely upon a scientific conference held in 1981 at Boulder, Colorado, James Oberg's latest book does an admirable job of explaining why a manned mission to Mars may be both practical and necessary as a national or world-wide goal around the coming turn of the century.

Although it seems likely that the Russians plan some sort of mission, possibly as early as the end of this decade, it would be unwise to rely again on a sense of competition to goad the United States back into space — we all remember what happened after Apollo. Oberg's more reasonable arguments suggest that a manned mission to Mars need cost no more than Apollo, and would probably cost far less. Apollo had to develop a basic spaceflight capability, which we now have; much of the equipment required for a manned Mars mission has been or will be developed for quite different purposes. Further, the unit cost of the science accomplished on Mars would be far less than if many individual probes were built and launched to answer specific individual questions, which could be answered better on a single manned mission. The failure of Viking to provide conclusive evidence for the presence or absence of life on Mars — despite its being designed to answer that very question — is a case in point.

Another cost-reducing factor helping manned missions is that after the first mission, subsequent flights should be able to mine the martian environment for many of the resources required to support their operations. Largely self-sufficient bases would be possible by as early as the second flight. Such bases could then supply materials and logistical support for many other space operations throughout the inner solar system. The martian moons, Phobos and Deimos, for instance, may turn out to be our most accessible sources of volatiles for life support and rocket propellant. (See Bruce Cordell's article "The First Martians" in the May 1983 issue.)

And lest we forget, the most important justification of all is the science itself. As the most Earth-like of the terrestrial planets, Mars provides an invaluable analogue for processes so far studied only on Earth. Further, the martian polar caps could turn out to provide a long-term record of the solar constant — the Sun's total energy output. This alone, in a time of increasing concern about Earth's environmental stability, might be worth the cost of even the largest expedition.

Despite generally well-presented arguments, supported by excellent research, the book does show some signs of hasty writing. Awkward sentences and an overuse of parentheses make for unnecessarily difficult reading. This is, however, more of a nuisance than a problem.

Finally, I think a note of praise is in order for Stackpole Books, Oberg's publisher. A small independent company, it is producing an excellent, yet low-priced, series of forward-looking books on both astronomy and spaceflight which might not find a home elsewhere. Their efforts deserve some support if we wish works like these to remain in print. *Donald F. Robertson.*

Celestial Navigator Mark III
Roger W. Tuthill, Inc.
11 Tanglewood Lane, Box 1086A
Mountainside, NJ 07092
$192 per axis

Tuthill's Celestial Navigator Mark III consists of a pair of digital setting circles designed to fit all the popular Schmidt-Cassegrain telescopes. Two separate units are needed for outfitting a Schmidt-Cass — one each for the right ascension and declination axes. The declination unit reads in degrees and tenths; the other reads in hours and minutes of right ascension. (To use the Navigator on a Dobsonian scope, you'll need two identical units that both read in degrees and tenths.)

You can set the digital display of either unit to "Bright" mode for easiest reading or to "Dim" to conserve battery power. To save battery power even more, the declination unit can be left turned off until you have to take a position reading. You won't lose the reading even if the power is off because the declination unit uses a precision potentiometer to measure the telescope position.

The RA unit uses a digital counter that counts pulses generated by an optical encoder driven by the main gear on your telescope. The optical encoder is permanently attached to the scope base. A thin cable connects the encoder to the electronics package. (Unlike the other unit, the one for RA must remain turned on to retain the reading.) As with any other RA setting circle, the Celestial Navigator is accurate only if you have your drive motor running.

The construction of the two Navigator modules seems rugged enough, although somewhat crude in appearance. All the integrated circuits are in sockets for easy servicing — but you'd have difficulty repairing the units yourself, as the identifying marks have been removed from every IC!

Battery power is supplied by standard 9-volt transistor batteries: the declination axis uses one battery; the RA axis uses two. The units will run on regular transistor batteries, but you'll get better life out of alkalines. The declination unit draws 8.5 milliamperes when running in "Dim" mode and 10 in "Bright"; the RA unit draws 13 milliamps in "Dim" and 17 in "Bright." This is within the capabilities of the batteries, but a jack and plug are provided on the RA unit so that you can use an external power supply.

Installing the declination unit on my C-8 was easy. I simply removed the right-hand setting circle by undoing one screw and replaced it with a special screw and adapter. That's the right hand as seen from the eyepiece end of the telescope — a bit of necessary information that wasn't pointed out in the instructions. The screw packed with my units was one-quarter inch too long to fit the scope, but trimming it off was no bother.

The right ascension unit is more work to install. First, you remove the scope tube and then disassemble the motor base by removing the snap ring on the main shaft (use snap-ring pliers). Before drilling the three small holes needed to mount the encoder, you grind off part of the raised letters molded into the telescope's base so the encoder will sit squarely when attached. After drilling and tapping the holes, you attach the encoder with the two screws provided. If possible, I suggest you

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do the drilling and tapping with a drill press so the encoder will mount as perpendicularly as possible. At this point you fiddle around with the positioning of the encoder so its gear mates smoothly with the telescope's drive gear. Once you reassemble the base, you will probably have to adjust the fit of the drive motors to get rid of excess play.

I find that slewing the telescope in RA now takes a bit more effort because the encoder gear adds some loading. Not much, mind you, but you'll feel the difference. And by the way, if you do a lot of observing in really cold weather, you'd better use an AC power supply or a 12-volt lighter plug-in for power — those little batteries won't work their best when frozen.

I certainly enjoy using the Celestial Navigator. It makes finding elusive objects a lot easier when there are no convenient stars to hop off from. The large digits are easier to read than regular setting circles, although one digit of my RA display has a segment that glows dimly all the time, making it somewhat easy to confuse 5s and 6s. If you are reasonably careful about getting an accurate polar alignment first, they'll work well for you. And they'll be of particular value on permanently mounted scopes. *James R. Bailey.*

Cosmology and Astrophysics
Yervant Terzian and Elizabeth Bilson
163 pages, hardcover, $22.50
Cornell University Press (1983)

Eleven internationally known physicists and astronomers honor Thomas Gold in this volume of essays. Gold is one of the leading astronomers of his generation, known for his pioneering work in cosmology, plasma physics, radio astronomy, and planetary physics. Organized under three headings — cosmology, high energy astrophysics, and the solar system — the book reflects the breadth of Gold's scientific contributions. Black holes, pulsars, cosmology, and the theory of gravitation are discussed.

Astrophotography
Barry Gordon
120 pages, paperback, $12 (+ 50 cents postage)
Published by the author (1983)
[order from: 845 West End Ave.,
New York, NY 10025]

In 12 chapters and 8 appendices, the author discusses topics such as exposure, image size, the basic equipment you need, how to take photos of "easy subjects," optical systems, equatorial mountings and drives, guiding, etc. He provides exercises to work out (and their answers) in two chapters. The book is indexed, but has no photographic examples.

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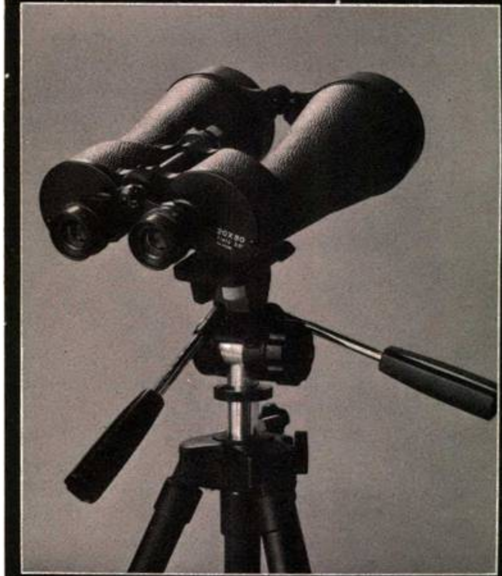

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Wm. Hartmann photo

eye on the sky

an eclipse in sagittarius

by Fred Schaaf

the wanderers

Several eclipses and occultations take place this month. Of these, however, only one — a partial eclipse of the **Moon** on the 25th — will be plainly visible to the naked eye from all of North America (although it will end too late to be seen completely from the eastern part of the continent). Meanwhile, Mercury and Venus are farthest west and east of the Sun, respectively, and all the outer planets are strung across the evening sky — except Mars, which nearly passes behind the disk of the Sun on June 3.

After last year's two total and dramatically ash-darkened lunar eclipses for the Western Hemisphere, can we expect any unusual sights with this partial eclipse? The northern part of the Moon will pass through the southern extremity of the umbra, the part least likely to be darkened by the El Chichon volcanic aerosols. It will, however, be interesting for naked-eye observers to determine when they can first see the penumbra and umbra on the Moon and whether there are any irregularities of illumination, color, or shape in the umbra.

From the eastern part of North America, the Moon is still immersed in the umbra as it sets. Observers may see the Moon in a dark band on the western horizon just before sunrise — the Earth's shadow, seen projected onto our atmosphere, stretching out a quarter million miles onto the Moon's limb. More information about the eclipse appears in The Backyard Astronomer.

During the month three bright planets are simultaneously visible in the early evening sky, and two dimmer ones are visible in binoculars. The faintest of these is Neptune, which reaches opposition this month.

For information on viewing the Moon, planets, and deep-sky objects with telescopes, see **The Backyard Astronomer**.

Scanning along the ecliptic, we encounter **Jupiter** and **Uranus** in Scorpius. Since the two planets were at opposition in the last days of May, they are visible almost all night long in June. Jupiter shines at magnitude -2.1 all month and pulls rather swiftly away from fifth-magnitude Uranus. Both planets, however, are still moving retrograde; they will turn back again in the summer — so that swifter Jupiter will again close the gap between them and cause a third and final conjunction as autumn begins.

While Uranus hangs a few degrees north of the globular cluster M-4 (visible in binoculars), Jupiter again meets the second-magnitude star Beta (β) Scorpii, in the head of Scorpius, for the second of three times this year. This conjunction occurs on the evening of the 22nd in North America, when Jupiter is only 10′ south of Beta — slightly closer than in January and much closer than in September. On the 22nd, the fifth-magnitude jovian moon Callisto is just past its greatest elongation from the planet and not much closer to Jupiter than Beta. Can you detect it with binoculars or — under superb conditions — with the naked eye?

While all the other bright planets are involved in many pairings and series of pairings this year, **Saturn** lingers without planetary companionship for most of the year. It does, however, spend one last summer in the neighborhood of Virgo near first-magnitude Spica. For the next two months, Saturn stays put — almost as stationary as Spica itself. The great ringed planet darkens in magnitude from +0.6 to about +0.9 in these two months, with most of the fading occurring in June. The planet's receding rings are least open on June 25, when they are tilted at an angle of 14.7° to our line of sight.

Venus is, as usual, the most spectacular naked-eye planet this month. It reaches a greatest eastern elongation of 45.5° (a bit less than usual) on North America's night of June 15-16 — though for people at mid-northern latitudes the planet was actually higher in the sky in April and May. The increased length of twilight at this time of year also contributes to making this one of the less favorable greatest elongations of the planet for northerners. But even with these reservations, Venus sets over three hours after the Sun for most of us in mid-June and is a striking sight.

This month the Evening Star brightens from magnitude –3.8 to –4.0. At the time of greatest elongation — or close to it — Venus appears half-lit in telescopes. How many days elapse between the evening and morning occurrences of greatest elongation, greatest brilliancy, and other Venus events? That eternal — and always similar — progression will be our main topic next month, as Venus heads toward inferior conjunction. Even as summer begins, we will find Venus setting noticeably sooner after the Sun each night.

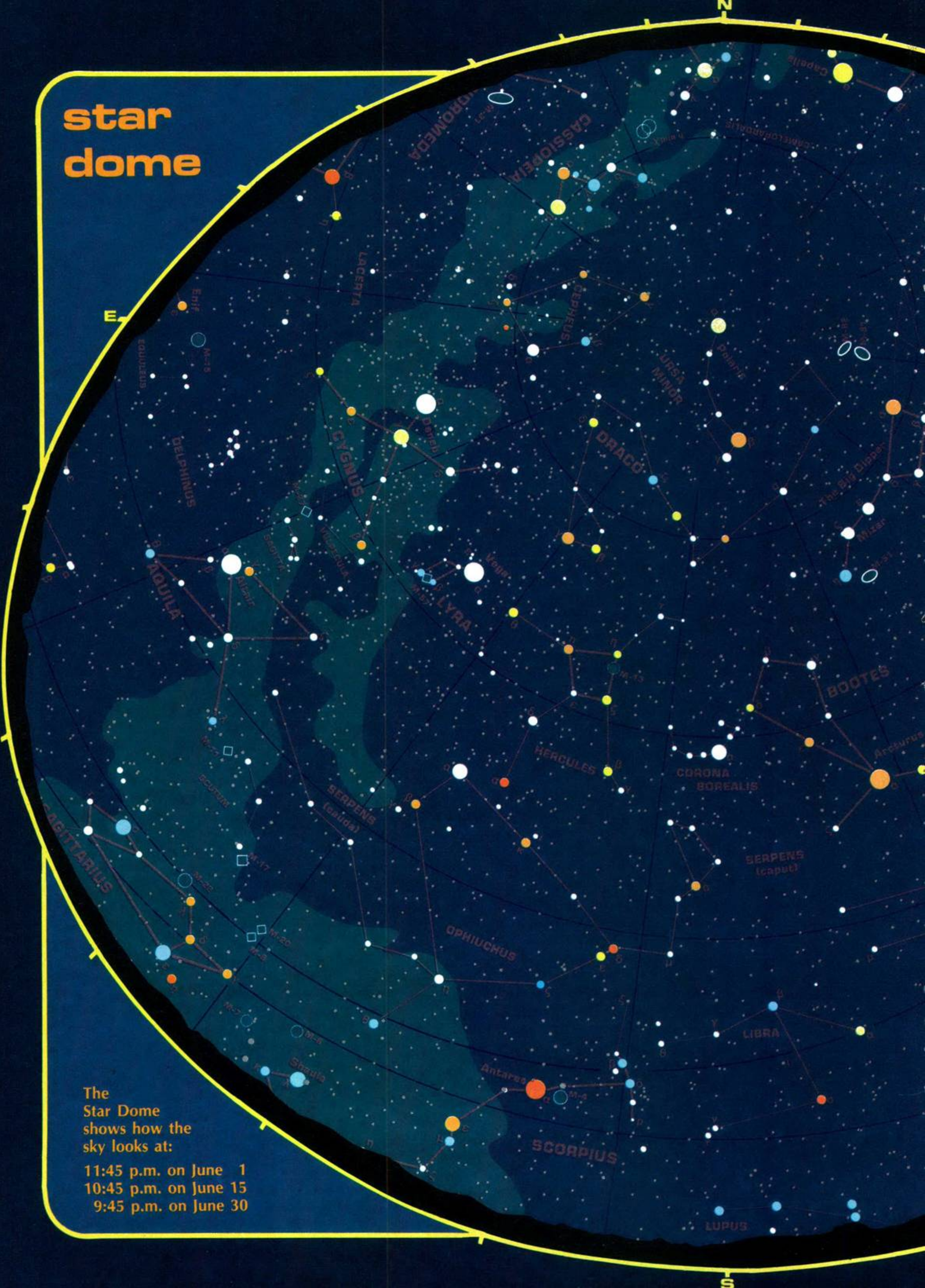
During June, watch Venus travel from south of Pollux, on past the Beehive in Cancer, until it finally approaches the star Regulus (a good conjunction is in store next month).

Mercury is also at greatest elongation (at 24:00 UT on the 8th) this month — but in the pre-dawn sky. This is a so-so apparition: the planet may be viewed most of the month, reaching its greatest altitude in mid-June. A fine sight for North American observers will be a close conjunction of Mercury and a very thin crescent Moon on the 9th (see The Backyard Astronomer for details on where an occultation will be visible).

The only invisible planet this month is

With the return of warm weather comes the arrival of the summer Milky Way — the busiest region of the sky for northern hemisphere observers. Visible in James Westlake's photo — which spans from Cygnus to Scorpius — are a number of bright clusters and nebulae, including M-8, M-20, M-6, M-7, M-22, M-16, M-17, and the North American Nebula. Westlake took the photo with his 16mm f/2.8 lens mounted atop a 6-inch reflector; he exposed 400 ASA film for 15 minutes.

star dome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CYGNUS
Deneb
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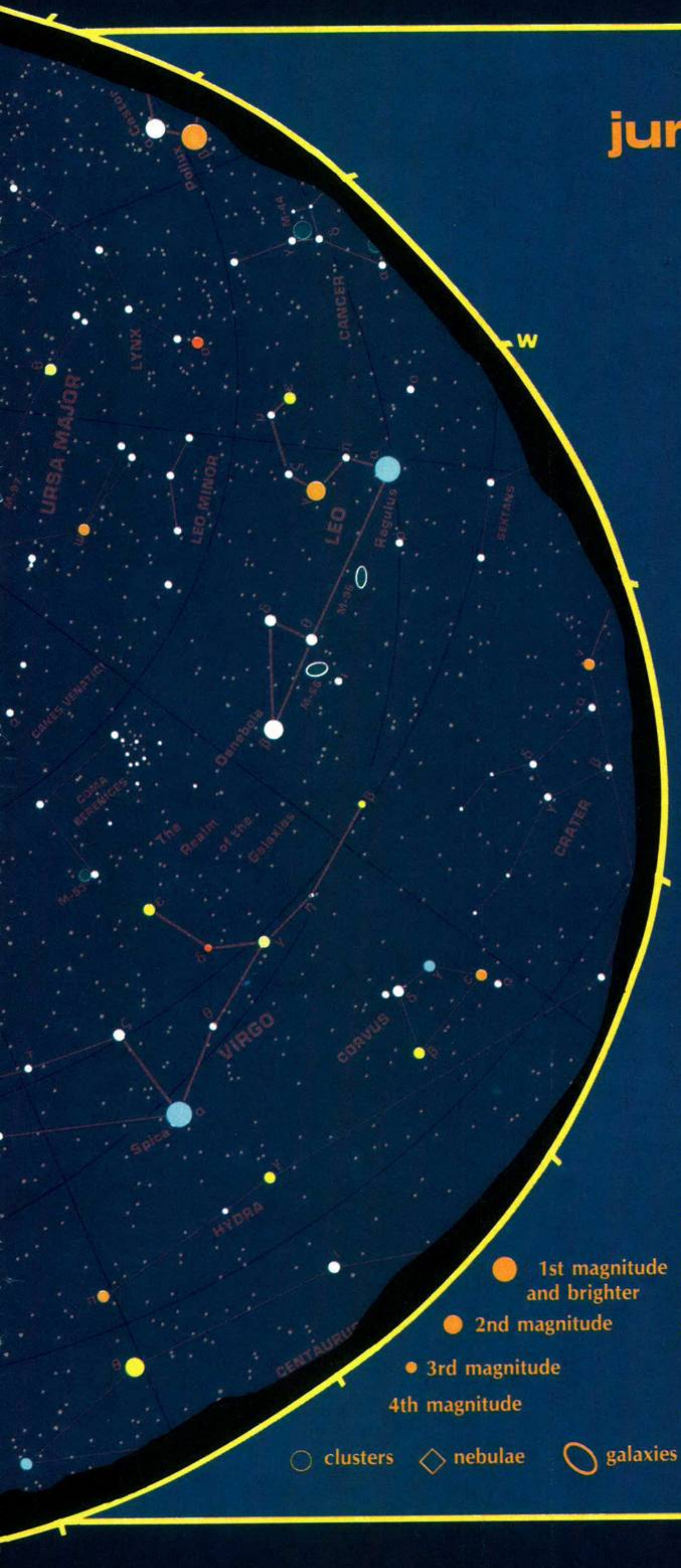
Polaris
M-81
M-82
DRACO
The Big Dipper
Mizar
M-51
VULPECULA
SAGITTA
AQUILA
Altair
Vega
LYRA
M-57
M-13
HERCULES
BOOTES
Arcturus
CORONA BOREALIS
SERPENS (cauda)
SCUTUM
M-11
M-17
M-16
M-20
M-8
SAGITTARIUS
M-7
M-6
Shaula
Antares
M-4
OPHIUCHUS
SERPENS (caput)
LIBRA
SCORPIUS
LUPUS

The Star Dome shows how the sky looks at:

11:45 p.m. on June 1
10:45 p.m. on June 15
9:45 p.m. on June 30


Castor
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M-44
CANCER
LYNX
URSA MAJOR
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LEO
Regulus
SEXTANS
CANES VENATICI
Denebola
COMA BERENICES
The Realm of the Galaxies
CRATER
VIRGO
CORVUS
Spica
HYDRA
CENTAURUS
W
1st magnitude and brighter
2nd magnitude
3rd magnitude
4th magnitude
clusters
nebulae
galaxies

june sky almanac

1st	The Moon is at apogee early this morning: 251,480 miles.
2nd	Start looking for Mercury very low in the east-northeastern sky in the hour before sunrise. It will be visible there until the end of the month.
3rd	The Moon is at First Quarter at 5:07 p.m. EDT.
8th	Mercury is at greatest western elongation from the Sun this morning: 24°.
9th	For most of the continent there will be a conjunction of Mercury and the Moon just before sunrise — for the east and northeast, there'll be an occultation of Mercury (see text and Backyard Astronomer).
11th	The Moon is New at 00:37 a.m. EDT; there is a total solar eclipse in Indonesia.
13th	The Moon is at perigee early this morning: 225,278 miles. Tonight, the Moon will lie to the lower right of Venus in the evening sky.
14th	Look for the Moon to the upper left of Venus this evening.
16th	Venus is at greatest elongation from the Sun this morning: 45°.
17th	First Quarter Moon is at 3:46 p.m. EDT.
19th	Neptune reaches opposition.
21st	The solstice is at 7:09 p.m. EDT; summer begins in the northern hemisphere.
22rd	The Moon will pass north of Jupiter and Uranus tonight.
24th	The Moon will pass north of Neptune tonight.
25th	Full Moon is at 4:32 a.m. EDT; there is a partial lunar eclipse (see text and Backyard Astronomer).
28th	The Moon is at apogee this evening; 252,059 miles.

Richard A. Keen made this photograph of last December's lunar eclipse with a 55mm f/1.8 lens and a 25-second exposure on 400 ASA film. The sky appears bright due to the glare of streetlights reflected by the newly fallen snow. This month a partial lunar eclipse occurs in Sagittarius.

Mars, which reaches conjunction with the Sun on June 3 and nearly passes behind its disk. Last month we posed the question of whether there can ever be a transit of Earth across the Sun as seen from Mars. The answer is yes, and a good story by Arthur C. Clarke called "Transit of Earth" dramatizes the next such event, which will occur on May 11 of next year and then not again — writes Clarke — for another century.

the starry sky

As Corvus skims low in the southwest, like the sail of a departing ship, and Leo declines toward Venus, it is clear that spring is almost over.

Midway between Saturn and Spica (gold and blue-white) in Virgo, and Jupiter and Antares (yellow-white and red) in Scorpius, we find a dim stretch of the zodiac occupied by **Libra** the Scales, whose pattern is a diamond nearly bisected by the ecliptic. **Alpha** (α) **Librae** is very close to the ecliptic and is a wide double. Most of us need binoculars to see the fifth-magnitude companion less than 4′ of arc away from the second-magnitude primary, but if you get excellent conditions, by all means test your unaided vision on this challenge.

Beta (β) **Librae** is slightly brighter at magnitude 2.6. It is worth observing, if only to check out two old claims about it: (1) that it was once much brighter; (2) that it is plainly green. Could Beta be an unusual variable star? What color do you find it to be with naked eye and binoculars?

It is difficult to patiently study Libra when brilliant Scorpius and Jupiter loom nearby. The stars of Libra were once the dim claws of Scorpius; now his westernmost stars are the conspicuous north-south line that forms the head of Scorpius' carapace. The ecliptic passes through this line near prominent star **Beta** (β) **Scorpii**. Jupiter is close to the star this month, but twelve years (one Jupiter orbit) ago, the planet occulted the Beta Scorpii system. We have records of Beta being occulted by the Moon way back in 295 B.C.; Ptolemy states that it was nearly occulted by Mars on January 17, 272 B.C.

The brightest star in Scorpius is **Antares**, whose reddish color earned it the title "Anti-Ares" — against Mars, the rival of Mars in redness. Early this month, when Antares is at opposition with the Sun, Mars is at conjunction with the Sun. The great stellar rival of Antares, winter's ruddy Betelgeuse, always sets at almost the same time that Antares rises (for mid-northern latitudes). Is it possible to glimpse the two in the sky at the same time from the United States and Canada? The best and most convenient time to try would be in early or middle spring.

Very prominent on June evenings is another bright star notable for its color, **Arcturus**. Some observers call it golden-yellow, but most agree that it has a definite orange tinge.

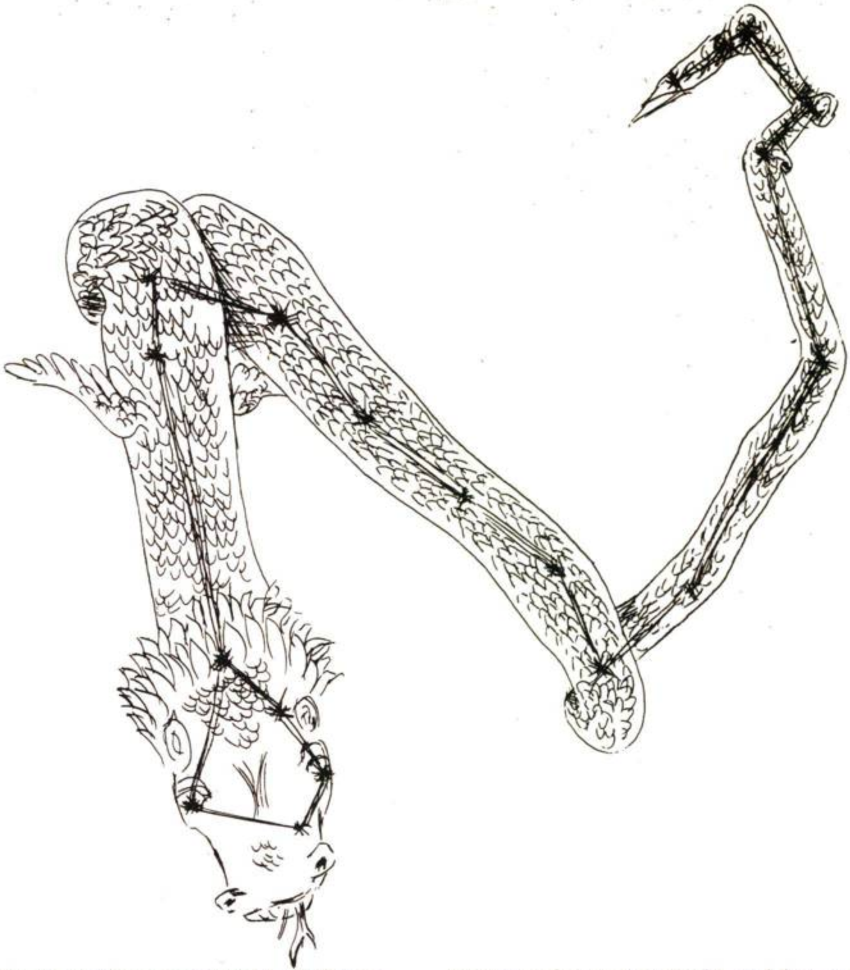
Just north of a line drawn from Antares to Arcturus is **Serpens Caput**, the Serpent's Head. Its brightest star is called **Cor Serpentis** — the "heart of the snake." It is a pretty sight in binoculars beside fainter **Lambda** (λ) **Serpentis** and is also a good reference point for finding the bright globular cluster M-5, which is visible in binoculars. Like Hydra's neck and head, now setting while the rest of Hydra extends up to Libra, the head and neck of Serpens sticks up just above the celestial equator.

North of Serpens Caput is a fine ornament of the heavens, **Corona Borealis**, the Northern Crown. It is composed of a semicircle of stars equally spaced and about equally bright. The lone bright star is **Alphecca**, also called Gemma. Always check the pattern of Corona for the possible intrusion of a "new star" — you might be seeing another rare flare-up of the recurrent nova called the "Blaze Star."

Bluish **Vega** is climbing in the eastern sky; it is the apex of the Summer Triangle, which is made up of three first-magnitude stars.

This month is a good time to examine a constellation that is often overlooked, yet always visible — **Ursa Minor**, the Little Bear. The two bright stars on the outside of this dipper's bowl, **Kochab** and **Yildun**, are nearly 20° from the North Celestial Pole, which **Polaris** almost marks. Ursa Minor is more easily visible for most of us when it is poised above the Pole — at this time of year, this occurs early in the evening. Most of Ursa Minor is, unfortunately, too faint for light-polluted skies.

Making a huge loop almost halfway around the Little Dipper is **Draco**, the Dragon. His head moves up to a prime evening viewing position next month with other fine constellations like **Hercules** and **Scorpius**.



skylore

Draco the Dragon is a formidable figure in legend; the constellation was once even more impressive in size and placement than it is today. Unlike Hydra, which was once much shorter (see April Skylore), Draco was once much longer. The ancient Chaldeans pictured Draco extending on down in front of the Great Bear — where we now place Lynx and Camelopardalis. As late as the 17th century, some books portray him as clasping both of the Bears in his great coils.

Another diminishment of Draco's ancient grandeur occurred around 600 B.C. when, according to Strabo, Thales of Miletus formed the constellation Ursa Minor from stars which previously were Draco's wings. A look at any good star map clearly shows how the handle of our Little Dipper is a fine outer curve to the wings.

Why did Thales suggest this change? Because these stars were a better navigational guide to true north than Ursa Major, which the Greeks had previously used. In Thales' day there was no one bright star near the North Celestial Pole, so the entire constellation of Ursa Minor was useful. As many readers may know, Draco's star Thuban was an earlier "north star" and was closer to the Pole than Polaris will ever be.

What is the origin of Draco? That may be as difficult to determine as the origin of dragons themselves. Perhaps the earliest dragon-like creature we know of in mythology is the Mesopotamian chaos-monster Tiamat. But is such a creature any more a dragon than the vast and horrible mixture of serpent and whirlwind which the Greeks called Typhon? We can not always tell from the old tales whether they are about giant snakes, other strange serpent-like creatures, or true dragons. Of these three categories, the constellation Serpens fits the first, Hydra and Hydrus the second, and only Draco the third.

Of course it is debatable just what constitutes a true dragon; the word has certainly been misapplied and overextended. The Chinese dragon is very different from the Western dragon: The Chinese version, says Jorge Luis Borges, "is divine and is like an angel that is also a lion." It appears in many forms, and could assume many forms. Some of them have wings, and some don't. As for Western dragons, must they all have wings? Certainly many authorities on dragons, including J.R.R. Tolkien, think so. And it is interesting to ponder whether the tradition of wingless dragons owes its beginning completely to Thales' practical alteration of Draco.

Whatever the case may be, dragons are one of fantasy's greatest inventions — unlike most imaginary creatures, a dragon seems to be more than just an obvious composite of real animals or a real animal with a minor alteration. Also, as Tolkien's dragons Glaurung and Smaug show, a dragon in a good fantasy story is more than just a fearsome physical danger. Tolkien's dragons (which were influenced by the dragon in Beowulf and the great Norse dragon Fafnir) also represent human moral peril, and powerfully exemplify the kind of despair and misery — the lessening of life — which evil brings to those who practice it.

We have no real evidence that Tiamat was represented in the stars of our Draco, though the Jobeses suggest that in the Babylonian god Marduk's defeat of Tiamat "the north wind carried away her blood, which showed as streaks high in space from time to time." Marduk, having composed heaven and earth from her body, placed another dragon around the Pole to guard the dome of heaven.

We also have no evidence that such Japanese dragons as Koshi and Izanami were represented by Draco's stars. Neither the world-surrounding Midgard Serpent of the Norsemen nor the monstrous snake Python, which Apollo killed, seems to be a true dragon.

We find some of the best candidates for Draco-like dragons in Greek mythology: our Draco could be the dragon fought by Cadmus. It is said that Cadmus sowed the dragon's teeth as seed, producing an instant crop of warriors who fought each other until there were just five survivors. Then they helped Cadmus found Thebes. Some of these teeth were later planted by Jason — and some people say it was a dragon that guarded the Golden Fleece.

Draco is most likely associated with yet another guardian, Ladon — the protector of the tree bearing the golden apples in the Garden of the Hesperides. Hercules shot this dragon to obtain the apples, and we see the strongman's forward foot placed upon Draco's head.

The fact that Draco never sets makes it a good symbol of vigilance and a fit guardian of the Pole — it curls almost halfway around the Pole at its high declination and covers almost 12 hours of right ascension. When Thuban was the Pole Star, says R.H. Allen, the rest of Draco was like the hands of a clock whirling counterclockwise around the Pole. But Draco is not just a Pole-guard of past ages: right in the midst of the constellation, surrounded by the first bend, is the point around which Earth's North Celestial Pole precesses — the North Ecliptic Pole.

equipment atlas

computing the skies

by Claudio Fabi

Several years ago I bought one of those little Sinclair ZX-80 computers. After playing around with it for a while, I put it away on a shelf. When the 8K BASIC ROM came out, I purchased one and used it a bit, but then the computer wound up back on the shelf again.

Recently, my daughter took a course in BASIC. Sure enough, down came the Sinclair once more — but this time to stay, I think. Though it certainly has its shortcomings, even this tiny, limited computer is far better than a calculator for many astronomical computations, because it makes long calculations easy and accurate. Calculators are really stupid — they're entirely dependent on you to hit the right keys in the right sequence every time you go through the algorithm. On the other hand, while computers are far from foolproof, they are delightful by comparison: once you have written and debugged the program, it doesn't matter how long the numbers are or how complicated the problem is.

Anyway, I started to write some simple astronomical programs for the ZX-80 — up to the limit I could squeeze in without additional memory. Three of my programs were derived from the article "Alt-Azimuth Setting Circles" by Paul Burke in the April 1982 ASTRONOMY, an article you should read over before you launch into programming these calculations. (It has an error in it regarding how to determine the quadrant for azimuth — see Ooops! in the July 1982 issue — but the programs listed here take this into account.)

When I began to use my computer, I was faced with the problem that the ZX-80 lacked sufficient memory; the solution was to break the routines up into three separate programs. Admittedly, this memory problem is almost unique to the ZX-80 — you avoid it with the ZX-81 (also known as the Timex Sinclair 1000) or any other computer with a more capacious memory. You should have few difficulties in stringing the three together if you want.

In practice, I run the sidereal time program first. After I compute my local sidereal time, I set the time on an old wind-up clock that has been adjusted to gain four minutes a day. Although this doesn't give split-second accuracy, having sidereal time to within a minute or two is good enough for most search-and-identify purposes, which use the other two programs.

Editor's note: The programs that Mr. Fabi sent with his article were, we felt, too "machine-specific" to be run as supplied. Although the ZX-80 was a popular computer, it has been replaced by a better one from the same company — and more important, the memory capacity of the average home computer is now well in excess of what the ZX-80 could offer. Few owners of home computers will find themselves as constrained if they were to purchase a machine today. This led us to re-work the programs to make them more general — and, we hope, more useful to the computing astronomers in our readership.

The BASIC employed is Microsoft's, but the programs have been deliberately constructed to convert to other dialects with as little fuss as possible. You'll notice that the listings are peppered with REM statements; these exist to make the contents and structure of the algorithms clear. If you find yourself tight for memory space, omit them.

You'll also notice that some of the variables incorporated into the program are set for a location other than yours (LAT, LONG, and TZ for example). You should make the appropriate changes in your copy of the program when you key it in. Another occurs in the sidereal time program, where the K1 variable changes annually; the values it has from 1983 to 2000 are tabulated in the box opposite — just update your program as needed.

And speaking of variables, you'll do well to declare at least the non-integer ones as double-precision. You still won't get your original numbers back again when you run an alt/az calculation followed by an RA/Dec computation — there is too much trig computation and conversion into and out of radian measure — but you'll get the best results your machine can do.

The most wonderful aspect of computers is the way they lend themselves to customization — so feel free to alter these routines in whatever way you like to make them more convenient. And if you find them useful, drop us a line to say so.

info sources

The following sources contain equations and algorithms for computing astronomical information. Try your nearest large public or university library for them.

"How to Calculate Horizon Coordinates," Robert Burnham, ASTRONOMY, Dec. 1978.
"Alt-Azimuth Setting Circles," Paul Burke, ASTRONOMY, Apr. 1982.
Algorithms for RPN Calculators, John Ball, John Wiley, 1978.
***Celestial BASIC**, Eric Burgess, Sybex, 1982.
***Practical Astronomy with Your Calculator**, Peter Duffett-Smith, Cambridge U.P., 1981.
Mathematical Astronomy with a Pocket Calculator, Aubrey Jones, John Wiley, 1978.
***Astronomical Formulae for Calculators**, Jean Meeus, Willmann-Bell, 1982.
Computers for Sea and Sky, Stephen J. Rogowski, Creative Computing, 1982.

Some of the books listed above date from the time when calculators were the mainstay for the computing hobbyist-astronomer. Despite this, the volumes still contain useful equations and are worth looking into. The other books contain programs in BASIC. (The ones marked with an asterisk are available from ASTRONOMY.)

Finally, don't overlook **The Astronomical Almanac**, which is published annually by the U.S. Naval Observatory and widely available in libraries.

local sidereal time, altitude & azimuth, and r.a. & dec.

```
10 REM -------- LOCAL MEAN SIDEREAL TIME ----
20 REM
30 REM K1, K2, and K3 are constants. K1 changes each year.
40 REM LONG is your longitude in decimal hours
50 REM TZ is the difference in hours between your
60 REM   time zone and Greenwich.
70 REM GMST is Greenwich Mean Sidereal Time
80 REM LMST is Local Mean Sidereal Time
90 REM
100 LET K1 = 6.60649392
110 LET K2 = .0657098232
120 LET K3 = 1.0027379093
130 LET LONG = 5.1234
140 LET TZ = 5
150 REM
160 REM ------- Input variables ---------------
170 REM
180 PRINT "Day of year";
190 INPUT D
200 PRINT "Local time (hours)";
210 INPUT H
220 PRINT "Local time (minutes)";
230 INPUT M
240 PRINT "Local time (seconds)";
250 INPUT S
260 REM
270 REM ------ Calculate quantities ----------
280 REM
290 PRINT
300 LET SDT = H + (M/60) + (S/3600)
310 LET UT = SDT + TZ
320 LET GMST = K1 + (K2*D) + (K3*UT)
330 IF GMST>24 THEN GMST = GMST - 24: GOTO 330
340 LET LMST = GMST - LONG
350 REM
360 REM ------- Print results ----------------
370 REM
380 PRINT "LOCAL MEAN TIME = "; SDT
390 PRINT "                GMST = "; GMST
400 PRINT "                LMST = "; LMST
```

```
10 REM ------------ RA & DEC CALCULATION ----------------
20 REM
30 LET LAT = 40.1234
40 LET RAD = 57.295775131
50 REM
60 REM ------------ Input Alt, Az, & LMST ---------------
70 REM
80 PRINT
90 PRINT "ALTITUDE";
100 INPUT ALT
110 PRINT "AZIMUTH";
120 INPUT AZ
130 IF AZ > 180 THEN AZ = 360 - AZ: LET FLAG = 1
140 PRINT "LOCAL SIDEREAL TIME (decimal hours)";
150 INPUT LMST
160 REM
170 REM ----------- Convert to radians ------------------
180 REM
190 LET A = ALT/RAD
200 LET AZR = AZ/RAD
210 LET L = LAT/RAD
220 REM
230 REM ----------- Calculate RA and DEC -----------------
240 REM
250 LET D = (SIN(A)*SIN(L)) + (COS(A)*COS(L)*COS(AZR))
260 LET DC = ATN(D/SQR(-D*D+1))
270 LET H = (SIN(A)-(SIN(L)*D)) / (COS(L)*COS(DC))
280 LET HC = -ATN(H/SQR(-H*H+1))+1.5708
290 LET DEC = DC*RAD
300 LET HA = HC*RAD
310 IF FLAG = 1 GOTO 330
320 IF SIN(HC)>0 THEN HA = 360 - HA
330 LET HAH = HA/15
340 LET RA = LMST - HAH
350 IF RA<0 THEN RA = RA + 24: GOTO 350
360 REM
370 REM ----------- Print out results -------------------
380 REM
390 PRINT
400 PRINT " RA = "; RA
410 PRINT "DEC = "; DEC
```

```
10 REM --------- ALT/AZ CONVERSION -------------
20 REM
30 REM LAT is your latitude in decimal degrees
40 REM RAD is 1 radian in degrees; a constant
50 REM
60 LET LAT = 40.1234
70 LET RAD = 57.295775131
80 REM
90 REM --------- Input object's position ---------
100 REM
110 PRINT "RA (hours)";
120 INPUT RH
130 PRINT "RA (minutes)";
140 INPUT RM
150 PRINT "RA (seconds)";
160 INPUT RS
170 LET RA = RH + (RM/60) + (RS/3600)
180 PRINT
190 PRINT "DEC (degrees)";
200 INPUT DD
210 PRINT "DEC (minutes)";
220 INPUT DM
230 PRINT "DEC (seconds)";
240 INPUT DS
250 LET DEC = DD + (DM/60) + (DS/3600)
260 REM
270 REM --------- Input LMST & get HA ------------
280 REM
290 PRINT
300 PRINT "LMST (decimal hours)";
310 INPUT LMST
320 PRINT
330 LET HA = LMST - RA
340 LET HAD = HA*15
350 REM
360 REM --------- Convert to radians -------------
370 REM
380 LET L = LAT/RAD
390 LET H = HAD/RAD
400 LET D = DEC/RAD
410 REM
420 REM --------- Calculate Alt/Az -------------
430 REM
440 LET A = (SIN(D)*SIN(L)) + (COS(D)*COS(L)*COS(H))
450 LET AA = ATN(A/SQR(-A*A+1))
460 LET ALT = AA*RAD
470 LET AZ = (SIN(D)-(SIN(L)*SIN(A))) / (COS(L)*COS(A))
480 LET AZA = -ATN(AZ/SQR(-AZ*AZ+1))+1.5708
490 LET AZM = AZA*RAD
500 IF SIN(H)>0 THEN AZM = 360 - AZM
510 REM
520 REM ---------- Print out results -------------
530 REM
540 PRINT "      ALTITUDE = "; ALT
550 PRINT "       AZIMUTH = "; AZM
```

K1 Constants

1983 6.60649392	**1992 6.59468400**
1984 6.59057904	1993 6.64447896
1985 6.64037496	1994 6.62856504
1986 6.62446008	1995 6.61265112
1987 6.60854592	**1996 6.59673600**
1988 6.59263200	1997 6.64653192
1989 6.64242696	1998 6.63061704
1990 6.62651304	1999 6.61470312
1991 6.61059792	**2000 6.59878800**

leap years are in **bold face**

day of year

Calculate the day of year (needed in the sidereal time program) by adding the day of the month to the following monthly base numbers: January 0, February 31, March 59, April 90, May 120, June 151, July 181, August 212, September 243, October 273, November 304, December 334. Remember that in leap years you increase the day number by 1 for all dates after February.

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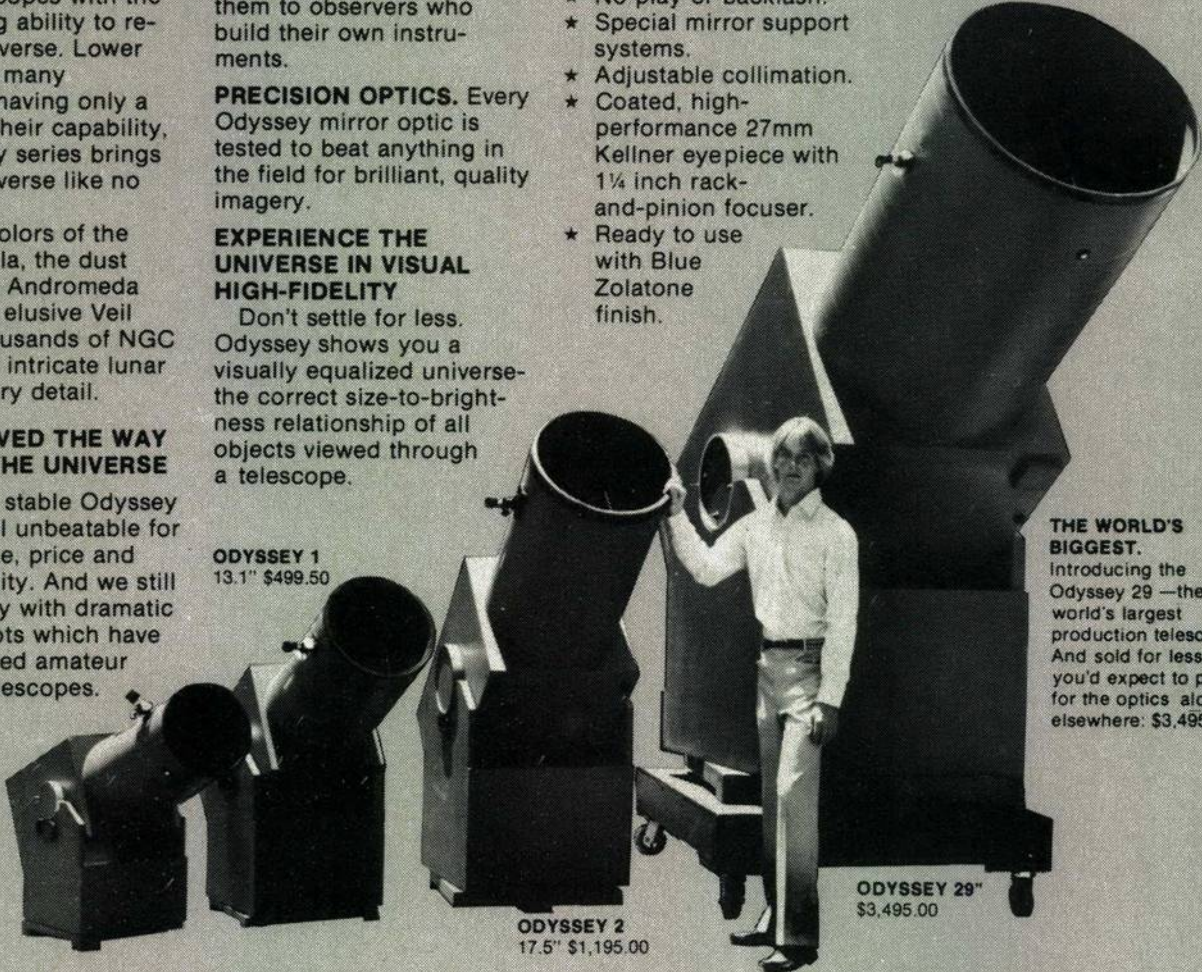

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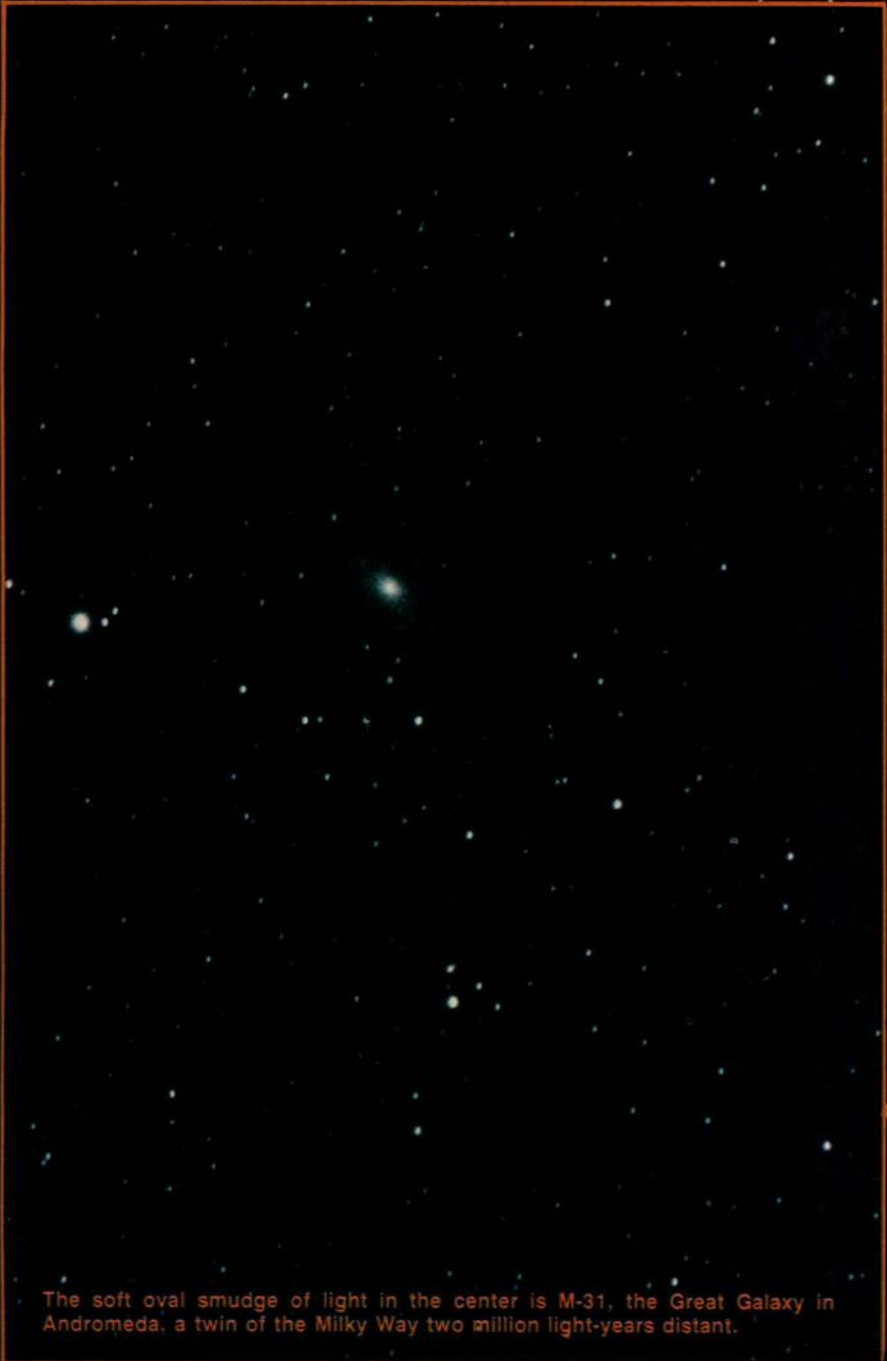


The soft oval smudge of light in the center is M-31, the Great Galaxy in Andromeda, a twin of the Milky Way two million light-years distant.

Although astrophotography is a word that has long sparked in me the wonder and excitement of exploring faraway places, it wasn't until recently that I actually gave it a try. I'm not sure just what the catalyst was, but it worked, and I've now taken the plunge. What I want to share with you here is not the experience of a veteran, but rather a few thoughts and impressions of a novice who has just made his first steps into a new universe. If you're thinking about getting involved in astrophotography, maybe my experiences can help.

When I got started, my first decisions concerned upgrading my equipment. I have had a 6-inch f/8 Newtonian since high school, but its mounting was nothing great, and it was clearly going to need a real overhaul before I could take photos with it. Since I'm nearly all thumbs in a workshop — and because I wanted to take photographs, not build quality optical instruments — I decided to buy a commercial 8-inch Schmidt-Cassegrain telescope. After looking over the ads, I was sure that the manufacturers offered enough accessories for these systems so that some combination of them would let me take acceptable photographs — and this has proved to be the case.

It sounds funny in retrospect, but I first became aware of the differences between visual and astrophotographic observing when it came time to load the car. For years I had simply packed the 6-inch, its tripod, and a set of star charts in my car, driven to a place outside the city, set them up, and started observing. The procedure was just as simple as it sounds. But preparing for my first venture in photography suddenly turned out to be like getting a Shuttle ready for launch. Just assembling all the stuff required a check list: telescope, tripod, wrenches, bubble level, drive corrector, power cord, illuminated eyepiece, camera mounts, camera, cable release — and, naturally, film.

The other big difference became

apparent when I went to set up the equipment at my observing site. With my old scope I would make a guess where north was, point the polar axis somewhere close to it, strap the telescope in, and get on with the observing; set-up took less than five minutes. You say that tree branch is in the way of M-31? No problem! Just pick everything up and move it until the view is clear. Having trouble observing near the North Pole? Easy! Turn the mount around so the polar axis points south and look all you like. (Don't laugh — for low-power visual observing, these seat-of-the-pants solutions work very well.)

But astrophotography was something else. No slapdash set-ups will do for picture-taking — no way. Polar alignment is a necessity, and it must be precise. My first attempt at this took a full hour, and despite the helpful directions I'd read, I still blew it. Well, learning takes time and setting up is becoming easier and easier with every trip I take — but all the same, the failure to get a correct polar alignment was my second biggest disappointment.

My first disappointment? Again, you'll laugh — it was dew! I should have thought of it, of course, but my old Newtonian *never* dewed up. Caught flat-footed and unprepared, the brave new adventure in astrophotography was cut short at 1 a.m. one night when the scope's corrector plate fogged over. Now my wife's hair dryer takes its proper place on the equipment check list.

But beside the differences in equipment and learning how to use it, there are other differences between visual and photographic observations that shouldn't be overlooked. In visual observing *you* are an explorer, with the telescope becoming an extension of your mind; it searches while you study and watch the universe around you. In taking photographs, however — even the easy-does-it, piggybacked kind shown on these pages — you are more detached from the skies. Your attention is focused closely on controlling an instrument that is probing the heavens, rather than on the heavens themselves. While taking photographs, you tend to lose much of the immediate excitement of direct visual observing — and unless you're prepared for this, you may feel a curious kind of letdown. But the excitement isn't lost — it's just deferred, since you'll get a tremendous sense of accomplishment when you get your prints or slides back from processing.

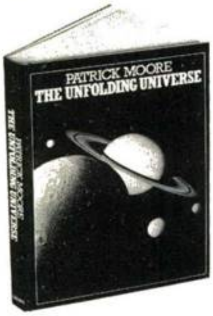
Although there is a considerable difference between astrophotography and visual observing, I'm delighted that I took the plunge. Something new has opened up to me — and at the same time, I can still pay visits to my old friends in the night skies.

Interested in astronomy since the sixth grade, Frederick Mendenhall is now an engineer with American Bell in Indianapolis.

These pages: The little spray of stars opposite is the Double Cluster in Perseus, while above is M-45, the Pleiades cluster in Taurus. All photos in this article were taken by the author with a 35 mm camera and a 135 mm f/2.8 lens riding piggyback on an equatorially mounted telescope. The exposures were 15 minutes on Tri-X.

The Unfolding Universe

by Patrick Moore



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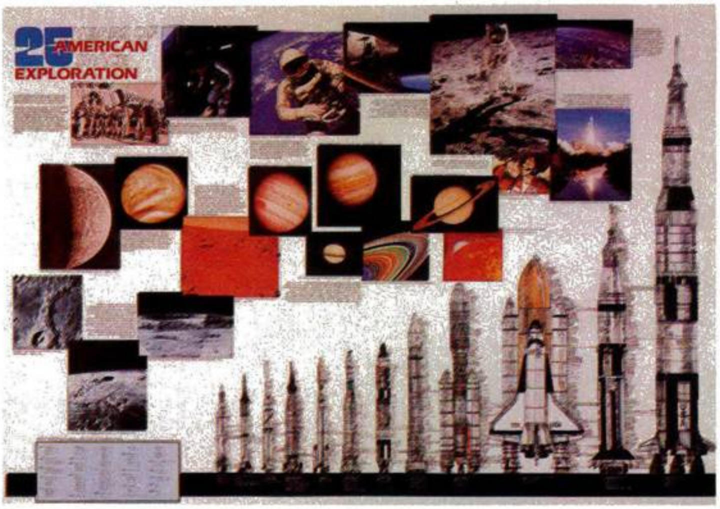

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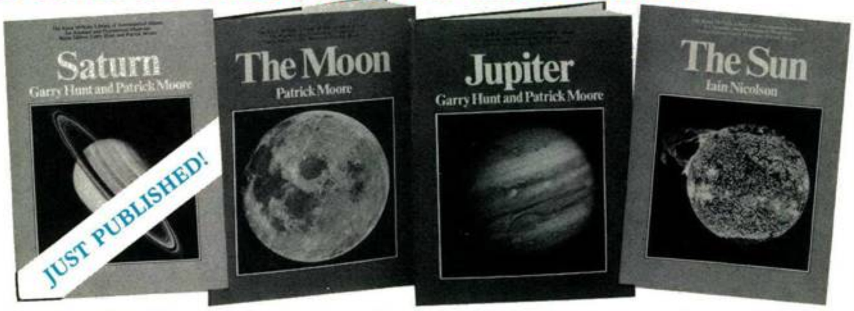

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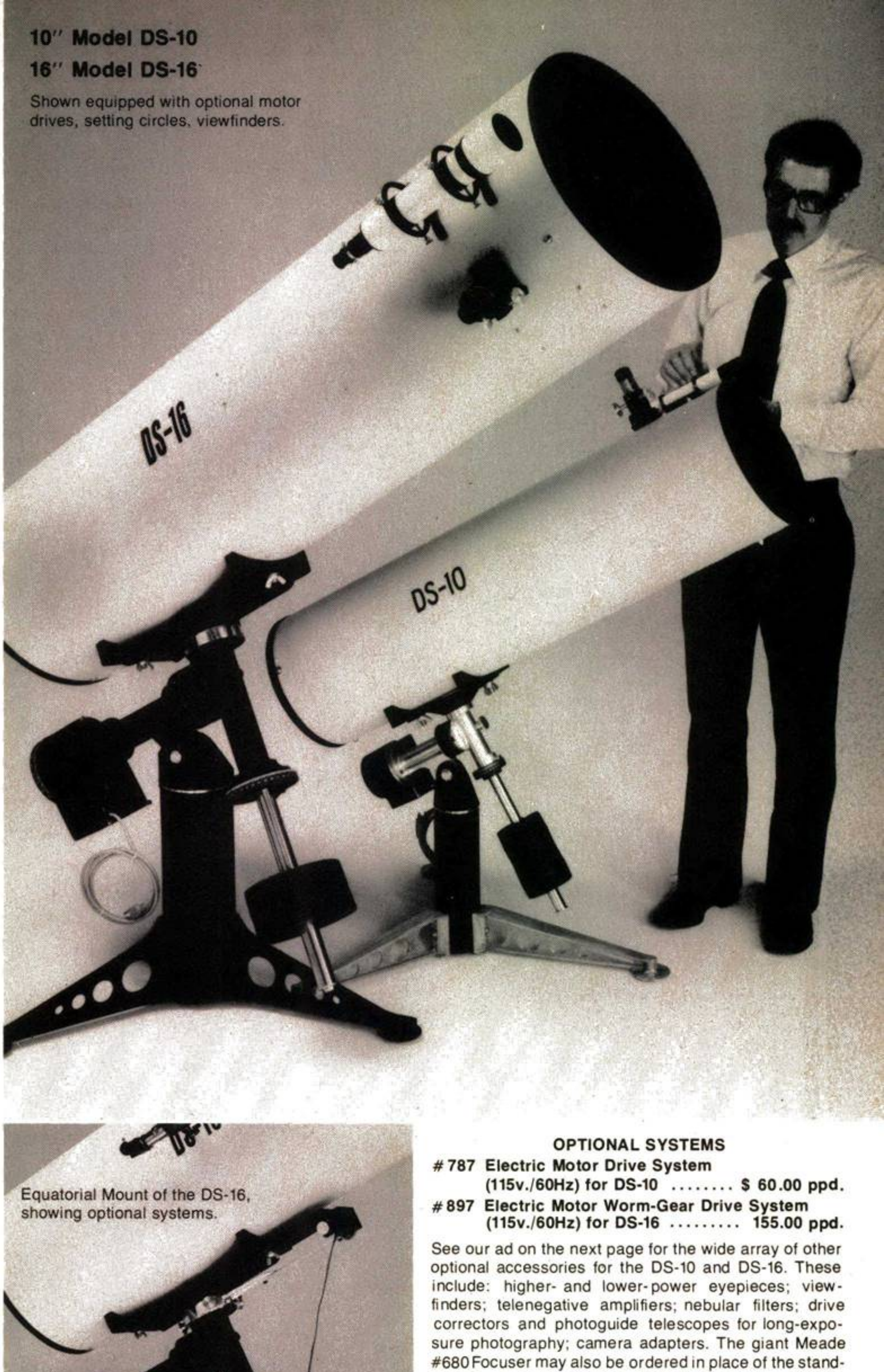
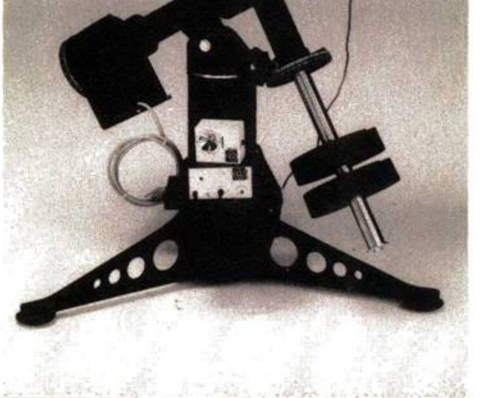


10″ Model DS-10
16″ Model DS-16
Shown equipped with optional motor drives, setting circles, viewfinders.



Equatorial Mount of the DS-16, showing optional systems.

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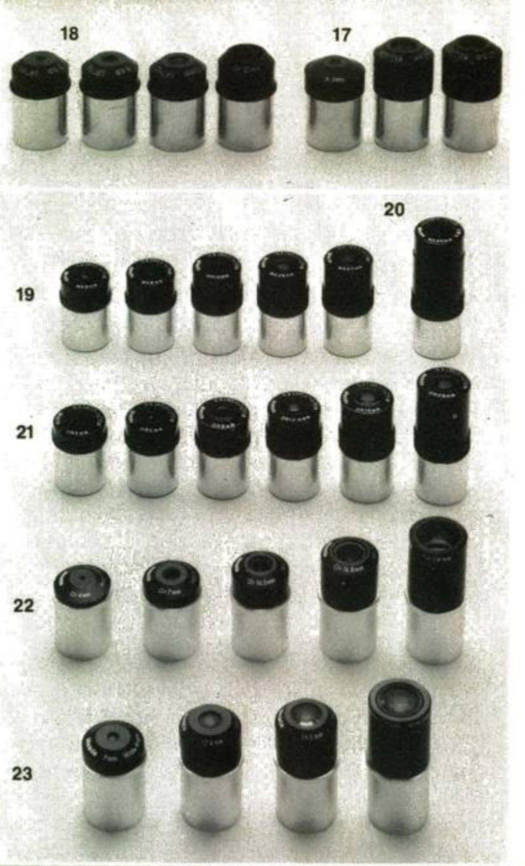

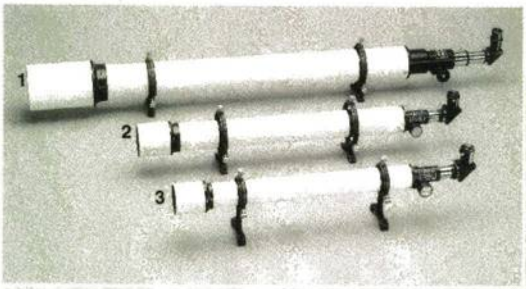

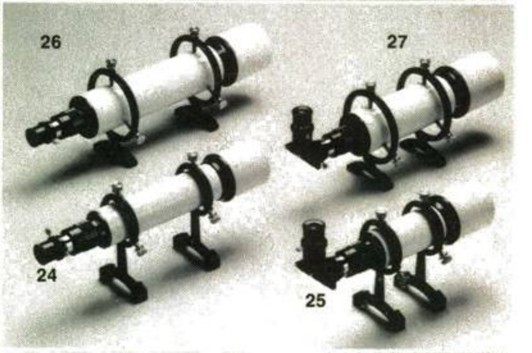

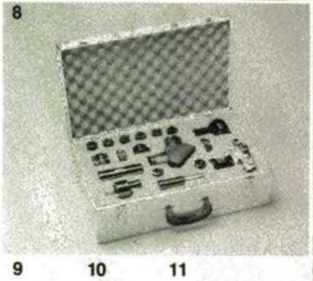

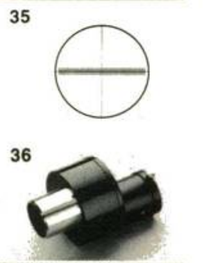

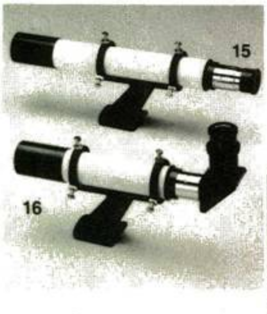

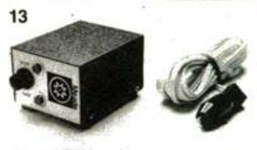

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Model 2120
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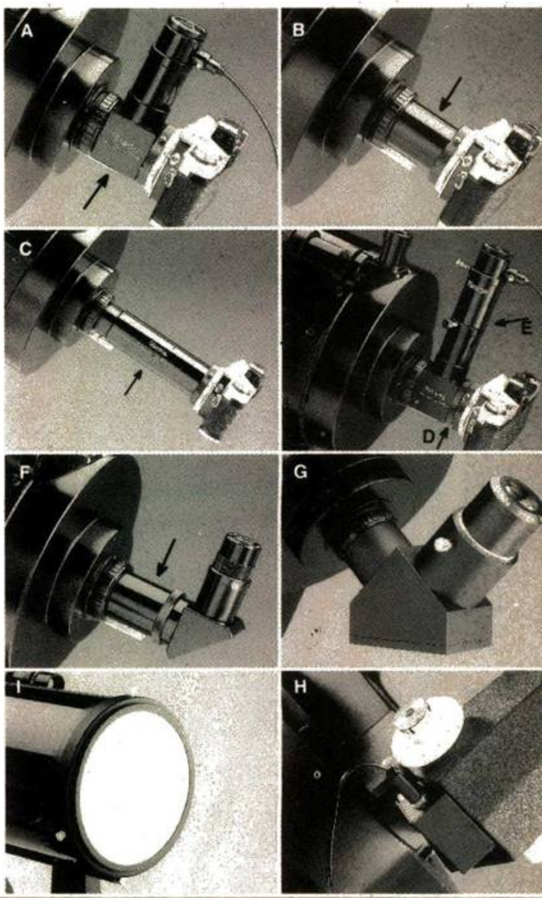

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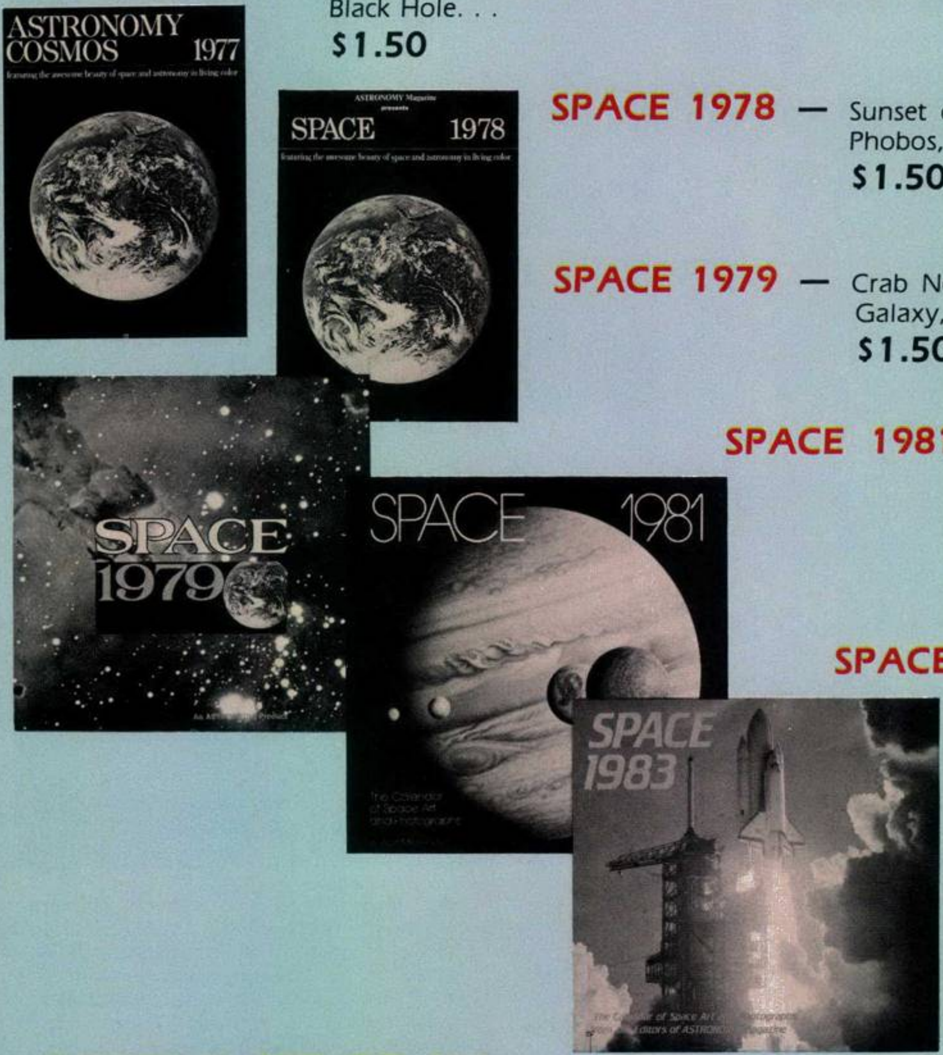

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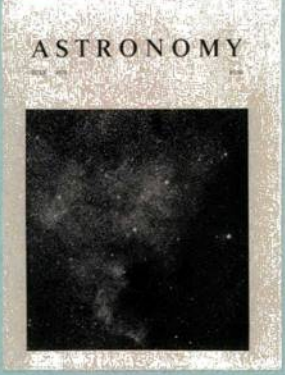

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ASTRO NEWS

Lunar, Martian Meteorites Found

At the recent Lunar and Planetary Science conference held in Houston, two meteorites, both found at separate locations in Antarctica several years ago, had their extraterrestrial pedigrees described in unusual detail: one of the meteorites came from the Moon, the other from Mars.

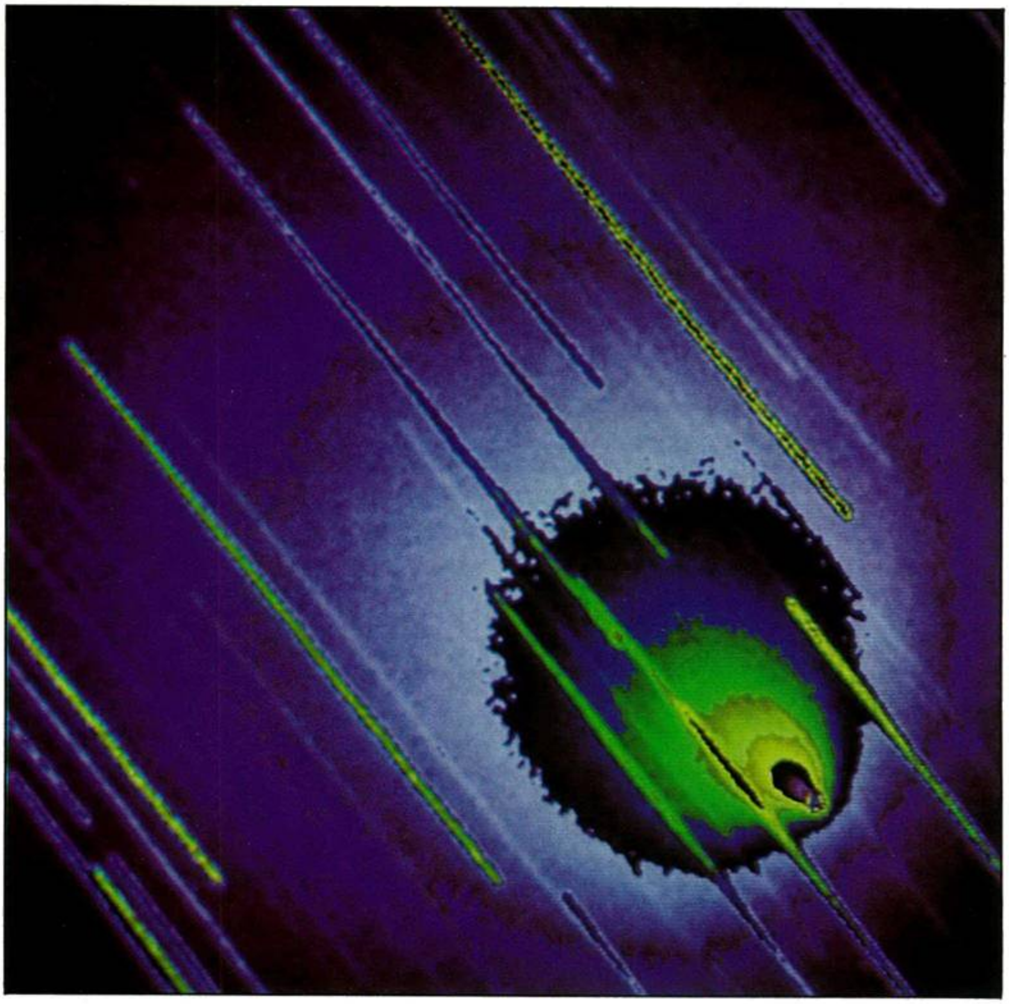
The lunar object was discovered in January 1982. It roughly resembles a greenish-brown golfball and weighs around an ounce. Researchers from many institutions have been working on the meteorite; their reports detailed the chemical, mineralogical, radioactivity, and gas-content studies, which have all shown that the object is most akin to rocks brought back to Earth from the lunar highlands during the Apollo program.

The other meteorite, found in 1979, is a lot larger: it weighs about 17½ pounds and measures some 8 inches across. The extraterrestrial identification is somewhat less certain for this rock, because we have as yet no samples of martian rocks to compare it with. But the best piece of evidence for a martian origin comes from studies of the rock's gases that were conducted by Robert O. Pepin of the University of Minnesota: the amounts of argon-40, argon-36, neon-20, and krypton-84 in the meteorite are all virtually identical with the amounts of these isotopes in the atmosphere of Mars as measured by Viking. In addition, the rock, a lava, was molten only 1.3 billion years ago — just yesterday, by meteorite standards — and Mars' volcanoes are thought to have been active then. Studies of the meteorite's mineralogy showed that it had been violently shocked some 180 million years ago, perhaps at the time it left Mars.

These objects pose a thorny problem for planetary scientists: just how do you take away a piece of a planet and land it on Earth, essentially undamaged? In both cases, impact is the most likely mechanism to accelerate the object to escape velocity. The lunar meteorite appears to have been ejected from the Moon by a large impact — possibly that of an asteroid — some 100,000 years ago, although no candidate crater has been identified. After wandering through space for a while, it was swept up by the Earth and fell to the ground.

In the case of the martian meteorite, the force of the blast must have been much greater since Mars' gravity is twice that of the Moon. But this comes dangerously close to a force that would have shattered the meteorite completely. Yet there the object is — and no scientist has yet worked out an airtight explanation for how it avoided being destroyed. But however it was removed, its chances for interception by the Earth were incredibly slim; as it happened, the meteorite spent some 2 million years drifting through the solar system before it was swept up by the Earth.

At this point, the martian identification has to remain as only extremely probable, and formal proof will probably have to await a sample-return mission to the planet itself.



Comet Encke is an old, quiescent, short-period (3.3 years) comet. This false-color digital image emphasizes differences in light intensity — a clue to Encke's structure. Courtesy S. Djorgovski, University of California, Berkeley.

Mystery Gap

Something strange is orbiting inside Saturn's rings — something which can provoke great bolts of lightning and herd ring particles from a mysterious gap, yet remains completely unknown.

Both Voyager 1 and 2 spacecraft detected electrostatic discharges similar to terrestrial lightning, which were later shown to originate not from the planet, as expected, but from somewhere within the B ring. Now D.R. Evans, J.H. Roming, and J.W. Warwick of Radiophysics Inc.; C.W. Hord and K.E. Simmons of the University of Colorado; and A.L. Lane of the Jet Propulsion Laboratory, writing in *Nature*, have used data from Voyager's radio telescopes to pin down the exact location of the lightning source.

The discharges were observed by both spacecraft to turn on and off with a period of about ten hours and ten minutes. The simplest explanation of this is that when the lightning source is behind the planet, it is "off." This rotation period corresponds to a circular equatorial orbit somewhere between 107,990 to 109,299 kilometers from the center of Saturn, and also suggests that the source is a discrete entity rather than something that affects the entire ring.

The next obvious question is whether there is anything unusual about the rings within the indicated area. Voyager 2's photopolarimeter observed the star Delta Scorpii as the rings passed between the instrument and the star; its data yielded a map of each ring's ability to stop starlight. In the scan, the B ring appeared abnormally opaque between 105,000 and 110,000 kilometers, suggesting that the area had more ring particles than nearby regions. Television photographs further revealed two 300-km bands bright in forward scattered light, suggesting that at least some of these particles are exceptionally small. And in the center of all this, the photopolarimeter observed a feature best explained as a dust-filled gap only 150 meters wide.

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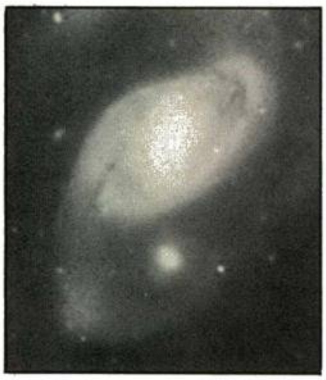
ASTRO NEWS

What lies within this gap, creating such a disturbance in the surrounding ring structure? We don't know, and Voyager's instruments provided no answers whatever — they could barely detect the gap. Like so many other questions that have come out of the Voyager encounters, this frustrating problem must await the next spacecraft from Earth. *Donald F. Robertson*



JPL/NASA photo

The Quasar Debate

Astronomer Jack Sulentic of the University of Alabama has found new evidence apparently indicating that not all quasars are extremely distant, highly luminous objects. In a paper published in the February 15, 1983, issue of *Astrophysical Journal*, Sulentic outlines the research he has conducted on a relatively nearby galaxy, NGC-4319, and a QSO named Markarian 205. Using the 5-meter Hale reflector on Palomar Mountain and the 4-meter Mayall telescope on Kitt Peak, the astronomer photographed the two objects, which lie close by each other in the sky. Sulentic has apparently recorded a luminous bridge of material between the two objects. This is baffling because NGC-4319 and Mrk 205 show markedly different redshifts, indicating that they lie at vastly different distances from Earth.

The "redshift controversy" is nothing new: it has existed ever since the discovery of quasars in 1963 by Maarten Schmidt of the California Institute of Technology (see "The Redshift Problem," ASTRONOMY, September 1978). Most astronomers believe that QSOs — as we see them — are extremely young and that they are the most distant type of celestial object, based on their respective redshifts — perhaps marking the "edge of the observable universe." In 1971 Halton C. Arp of Mount Wilson and Las Campanas Observatories suggested that a bridge of material existed between the two objects, but the majority of astronomers were nonplussed. A flurry of more conventional explanations surfaced: 1) the connection appeared because light from two objects smeared together in the plate emulsion, 2) it was caused by an interloper between the two bodies, or 3) Arp was just plain wrong.

Sulentic's luminous bridge of material offers the most concrete evidence to date for interaction between these two types of objects. "This is by far the clearest example of such interaction between a galaxy and a quasar," said Sulentic. "We have what may be an extremely young object being shot outward from the galaxy."

The controversy will probably continue, but unless Sulentic's data are refutable or an alternate explanation is found, this development may help redefine the term "quasar" — or at least place in doubt the accepted distances to these exotic objects.

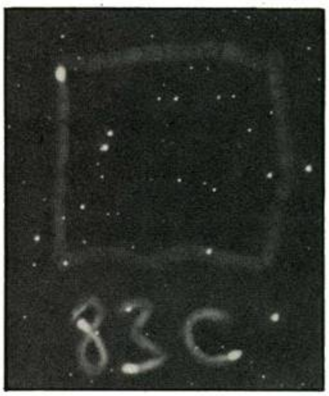
Pioneer 10 Leaves the Solar System

On June 13th, the unmanned spacecraft Pioneer 10 — launched in 1972 and the first craft to fly past Jupiter — will cross the orbit of Neptune, 2.8 billion miles from Earth. When it does, the craft will be farther out from the Sun than any known planet and will, for all practical purposes, have left the solar system. (Although Pluto is normally considered the outermost planet, its orbit is so eccentric that between 1979 and 1999 it will be inside Neptune's orbit — and Pluto will never again catch up with Pioneer.) Where Pioneer is now, sunlight is only about a thousandth as strong as it is near Earth.

Besides scientific experiments, both Pioneer 10 and its sister ship, Pioneer 11, also carry the famous "naked people" plaque — a depiction of the male and female of our species plus two schematic views that show the solar system and the craft's trajectory out of it, and where the solar system is, relative to several Galactic pulsars. In constructing the plaque, project scientists hoped that anyone who finds the craft in the ages to come will get at least some idea of who built it and when and where they lived. It will take about 850,000 years for Pioneer 10 to reach its first "close" encounter with a star system — that of Ross 248 — and it will miss that star by some 3.3 light-years.

But as it leaves the system, Pioneer's mission is far from over. Project engineers expect to be able to track the craft to a distance of about twice what it is now. This, they hope, will allow the instruments (which, with the exception of the now-defunct magnetometer, are all working well) to pinpoint when the craft penetrates the heliopause, the shock front where the Sun's electromagnetic domain gives way to the interstellar one. No one knows how far out this is: the heliopause could be crossed anywhere from 5 to 10 billion miles out.

Pioneer's course is also being monitored closely for evidence of any massive objects far from the Sun. Unexplained deviations in the motions of Uranus and Neptune — previously thought to be caused by Pluto — indicate that there might well be a tenth planet or a "dark star" companion to the Sun. In addition, Pioneer's great distance from Earth may also allow the detection of gravity waves.



Lowell Observatory photo

Comet Bowell-Skiff

Astronomers at Lowell Observatory in Flagstaff, Arizona, have discovered a new periodic comet, tentatively dubbed 1983c. On February 11 observer Brian Skiff made a series of wide-angle exposures with the 13-inch astrographic "Pluto" camera — the instrument used by Clyde Tombaugh to discover Pluto in 1930 — in search of faint asteroids. When Lowell astronomer Edward Bowell analyzed the plates, he found a curious fuzzy object on one of them, which in fact turned out to be the comet. After he reported the discovery to the Smithsonian Astrophysical Observatory, the official name for 1983c became Comet Bowell-Skiff.

Unfortunately, the comet was only a month short of perihelion when it showed up on the plate, shining at only 16th magnitude — so it isn't expected to be visible in amateur telescopes. Ed Barker at McDonald Observatory, who took spectra of the comet, stated that "it shows a continuum with a weak CN emission, but by and large it's just a typical faint comet." Comet 1983c is now heading out of the solar area and is expected to pass within 2 AU of Saturn in 1995, according to Bowell.

Ohio State's Radio Observatory Faces Eviction

It began like a bad dream for radio astronomers at Ohio State University. Summoned along with other Ohio State officials to a meeting with officials from Ohio Wesleyan University in early January, the researchers presumed that the discussion would center on the future of their massive research antenna near Delaware, Ohio.

What they heard may well have been the observatory's death sentence: the home of the world's longest-running radio search for extraterrestrial intelligence — as well as dozens of other important scientific discoveries — is facing eviction.

Some 25 years ago, Ohio State and Ohio Wesleyan universities entered into a joint agreement to operate a radio observatory. Ohio State agreed to supply staff, equipment, and expertise; Ohio Wesleyan provided the land. Both institutions were to have access to the facility for research. But over the years, it became apparent that only Ohio State faculty and students used the radio telescope. And now Ohio Wesleyan has announced that it sold the land the telescope sits on.

The observatory occupies about 2% of a 265-acre tract that the Delaware Country Club purchased from the university for the purpose of expanding its present 9-hole golf course to 18 holes.

"Legally, they may be within their rights," Robert Dixon, assistant director of the observatory, admits. "But morally and philosophically, it's preposterous!

"It's astounding to me that they just announced that an agreement was reached, giving us no opportunity to buy, lease, rent or anything."

That's not exactly correct, according to Thomas Wenzlau, president of Wesleyan. He says that Ohio State was informed officially at

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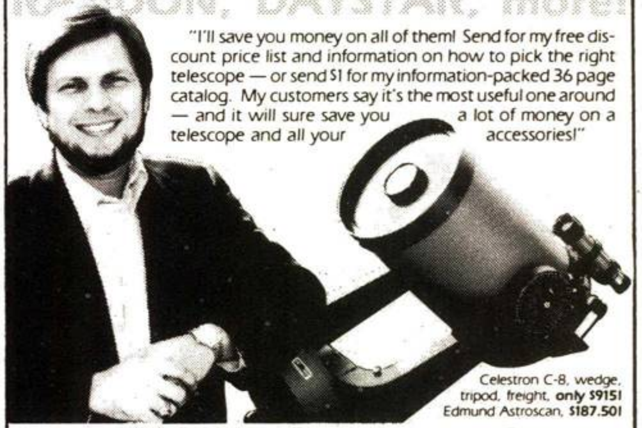

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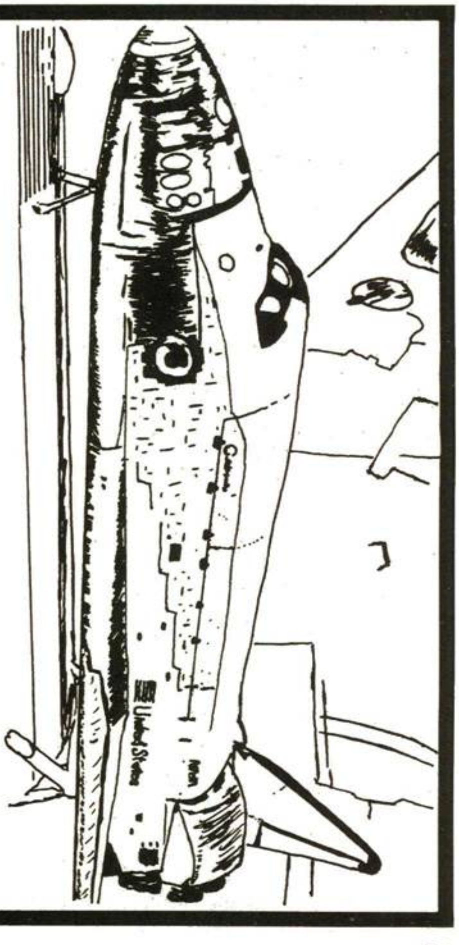

ASTRO NEWS

least twice about Ohio Wesleyan's desire to sell the land — once, in 1981, through a letter to a former Ohio State president and once in a letter to the current president last October.

"But did we go to them [Ohio State] and say 'We're going to sell the land. Would you like to buy it?' No, we didn't do that," Wenzlau says.

Larger than three football fields, the radio telescope is the fourth largest in the United States, according to John Kraus, emeritus professor of astronomy and director of the radio observatory.

It was here that Dixon, Kraus, and other astronomers discovered OH 471, a quasar 14 billion light-years away, which for 15 years was the most distant object in the known universe. It was here that they completed an all-sky survey of radio sources that added 20,000 new objects to the celestial ledger. And it is here that for the past decade, researchers have operated the world's longest-running continuous search for extraterrestrial intelligence.

When it was built during the 1960s, the telescope cost about $2 million; funds came chiefly from the National Science Foundation. Now it is funded largely by small grants from NASA. To replace the facility would cost nearly $5 million, according to Dixon and Kraus. And relocation of the equipment and massive antenna, while not impossible, is improbable because of the costs involved, most officials agree.

If Ohio State can't reach some kind of mutual agreement with the new owners for continued use of the facility, it will mean a radical change in the university's radio astronomy program, to say the least. While some work would continue, it would be of a different nature than that carried on at the Delaware site.

For Dixon, the situation seems bleak.

"This is the only radio observatory in the world where man is conducting a continuing search for other civilizations," he says. "There must be thousands of golf courses."

ASTRO CALENDAR

May 27-30	**Riverside Telescope Maker's Conference.** Big Bear, California. Contact: Clifford Holmes, 8642 Wells Ave., Riverside, CA 92503.
June 3-6	**Convention of the Mid-States Region of the Astronomical League.** William Jewell College, Liberty (Kansas City), Missouri. Contact: Tom Martinez, Chairman, 1208 Somerset Ct., Blue Springs, MO 64015.
June 8-12	**Texas Star Party,** Fort Davis, Texas. Annual meeting of the National Deep Sky Observers Society will be held in conjunction with the Star Party. Contact: T.S.P. '83, Dept. A, 2709 Colonial Dr., Carrollton, TX 75007. Phone (214) 242-4908.
June 10-11	**13th Annual Apollo Rendezvous and Telescope Fair.** Dayton, Ohio. Sponsored by the Miami Valley Astronomical Society and the Dayton Museum of Natural History. Contact: Coordinator — Apollo Rendezvous, 2629 Ridge Ave., Dayton, OH 45414.
June 13-19	**Joint Meeting of the Astronomical Society of the Pacific and the Western Amateur Astronomers,** on the Kona coast of the Big Island of Hawaii. Contact: Hawaii Meeting, A.S.P., 1290 24th Avenue, San Francisco, CA 94122.
June 19-22	**American Astronomical Society** (professional meeting). Minneapolis, Minnesota. Contact: AAS, 1816 Jefferson Pl., N.W., Washington, DC 20036.
July 8-10	**Connecticut River Valley Astronomers' Conjunction.** Northfield Mountain Center, Northfield, Massachusetts. Contact: Jack Megas, 311 Surrey Rd., Springfield, MA 01118.
July 14-16	**4th Annual Fairborn Symposium,** "Microcomputers in Astronomy." Fairborn, Ohio. Sponsored by IAPPP and AAS/SIGUMA. Groundbreaking for Fairborn Observatory one-meter telescope, July 15. Contact: Microcomputers in Astronomy, c/o Fairborn Observatory, 1247 Folk Rd., Fairborn, OH 45324.
July 15-17	**Convention of the Middle East Region of the Astronomical League.** Messiah College, Grantham, Pennsylvania. Contact: John R. King, Jr., 209 Louis Lane, Enola, PA 17025.
July 16-24	**Spaceweek.** For information and materials about how to organize and publicize pro-space events, contact: Ray Curtis, Spaceweek National Headquarters, P.O. Box 58172, Houston, TX 77258.
July 16-24	**Florida Spaceweek '83.** Many cities need people. Contact: Florida Spaceweek Committee, 993 Macco Rd., Cocoa, FL 32922.
July 22-23	**Spaceweek-Upstate,** a weekend for the amateur astronomer. Greenville, South Carolina. Contact: Piedmont Advocacy for Space, Box 197, Fair Play, SC 29643.
July 26-30	**ALCON '83** — national convention of the Astronomical League. Jacksonville, Florida. Contact: Michael Reynolds, P.O. Box 1170, Jacksonville Beach, FL 32250.
August 5-6	**Stellafane.** Springfield, Vermont. Contact: Dennis di Cicco, 60 Victoria Rd., Sudbury, MA 01776.

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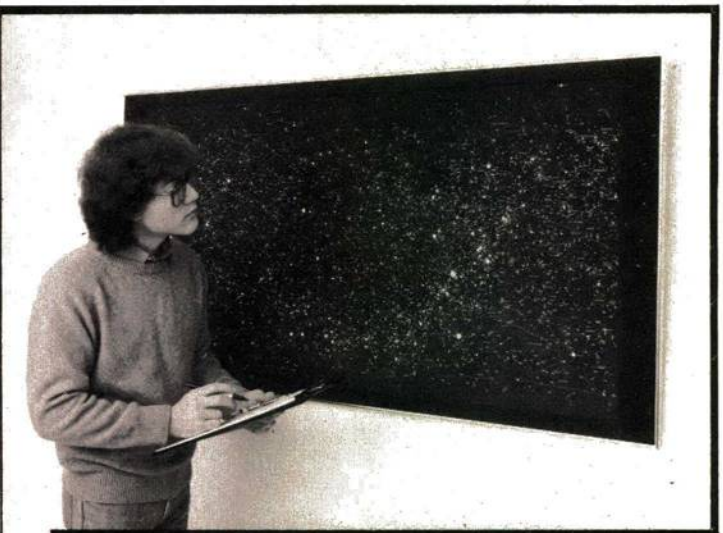

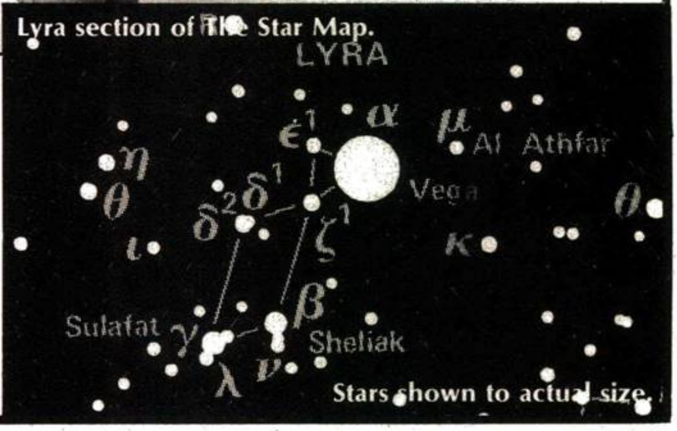

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COSMOLOGY on a COMPUTER

by Adrian L. Melott

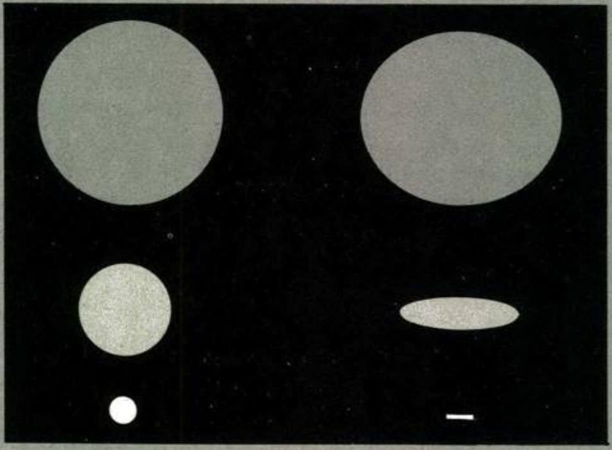
Part 1

Unlike most articles in ASTRONOMY, this is a personal narrative. By presenting the ideas this way, I hope to show some of the ways in which research proceeds and ideas develop. In my case, the primary tool has been computer simulations. But to set the stage for the computer simulations, I'll have to spend some time setting up the problem.

Perhaps you remember an earlier article that I wrote, "The Invisible Universe" (ASTRONOMY, May 1981). In it, I outlined some of the reasons why other astronomers and I think it is a reasonable hypothesis that most of the mass of our universe is in the form of elementary particles called neutrinos. Although it was formerly believed that neutrinos have no mass at all (like photons), there are experimental and theoretical indications that this may not be true. Let me recommend that you go back and read that article.

In the spring of 1980, I heard that there was some evidence that the neutrino had a mass. Astronomers had previously calculated that our universe should be filled with neutrinos to a density of about 100 per cubic centimeter, on the average, if they have a zero or small mass. So we can figure out how much mass density the neutrinos would contribute to the universe for any given neutrino mass. It turns out that even for a very small mass — smaller, in fact, than any other presently known particle with a mass — the neutrinos would outweigh all the stars in all the galaxies we can see!

Collapsing Gas Clouds



A spherical cloud collapses spherically (left) — but if it is ever so slightly flattened, the flattening increases as it collapses, resulting in a "pancake" (right).

There has been a problem in astronomy for about 50 years called the "missing mass" conflict. Simply put, it seems that there is matter that we can't see. For example, the velocities of galaxies in clusters of galaxies seem to be too great — the cluster should long ago have flown apart, because the gravity exerted by each of the galaxies on all the others is not enough to hold the cluster together. There must be something else there — something that doesn't shine like stars.

In the 1970s, evidence arose that galaxies like our own, which are not inside a crowded cluster, also have dark stuff surrounding them, outweighing the galaxy we can see. (See "Galactic Coronas," ASTRONOMY, November 1982.)

So I asked, "Could this dark stuff be neutrinos?" After mulling it over, I realized that one might test whether neutrinos could "fit" into a galactic halo. You see, neutrinos belong to a class of particles called fermions. Such particles obey a law called the Pauli Exclusion Principle — they avoid being crowded together, in a precise sense. Since we know the approximate density of the matter that surrounds galaxies, we can say how much mass each neutrino must have for the swarm of neutrinos to provide mass that explains our Galaxy's dark halo.

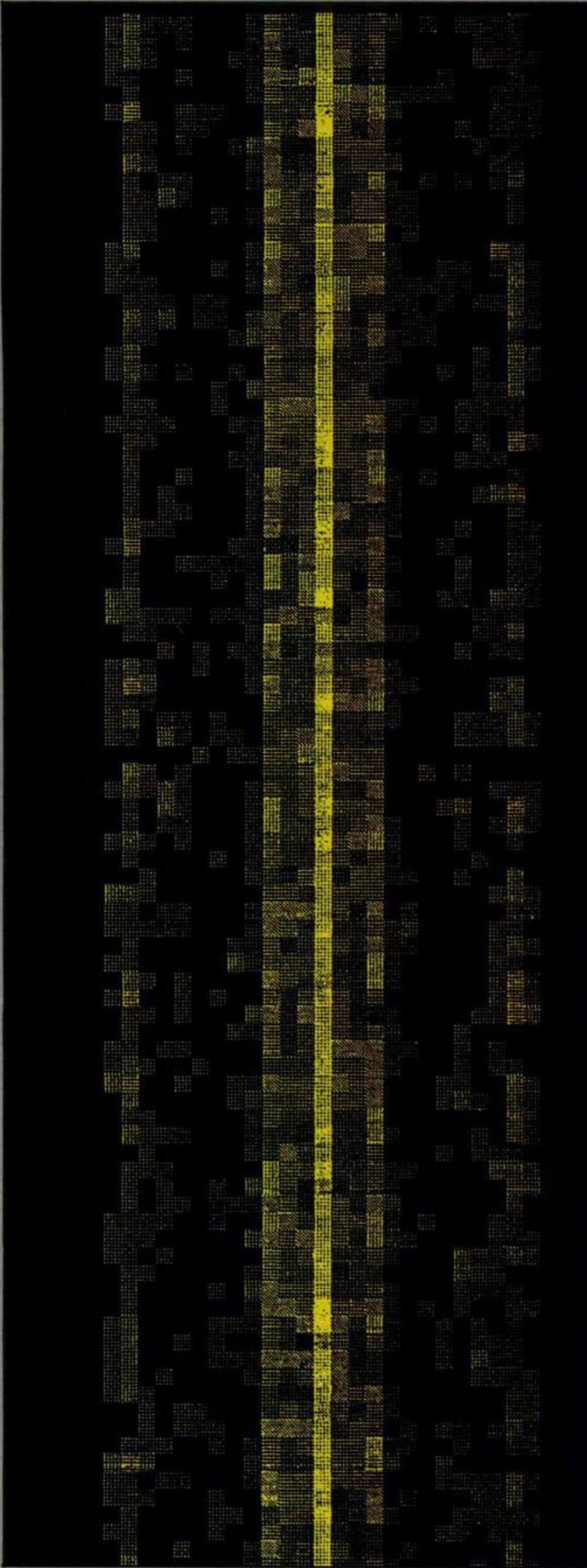
The answer is interesting. Depending on the uncertainties connected with the knowledge we have of the Galaxy, the mass is about $\frac{1}{10,000}$ the mass of an electron. This is about the same mass that would give our universe closure density. By "closure density," I mean just enough mass to exert a gravitational pull great enough to ultimately slow down and stop the expansion of the universe — and perhaps cause it to fall back again.

This coincidence between the properties of galaxies, the expansion rate of the universe, and a number called Planck's Constant, which tells us how closely we can crowd these particles, looks suspicious. In physics, coincidences like this sometimes tell us there is something important lurking behind the scenes. Of course, sometimes they are the result of pure chance and can lead us astray. We still don't know which is true in this case — and may not for a long time.

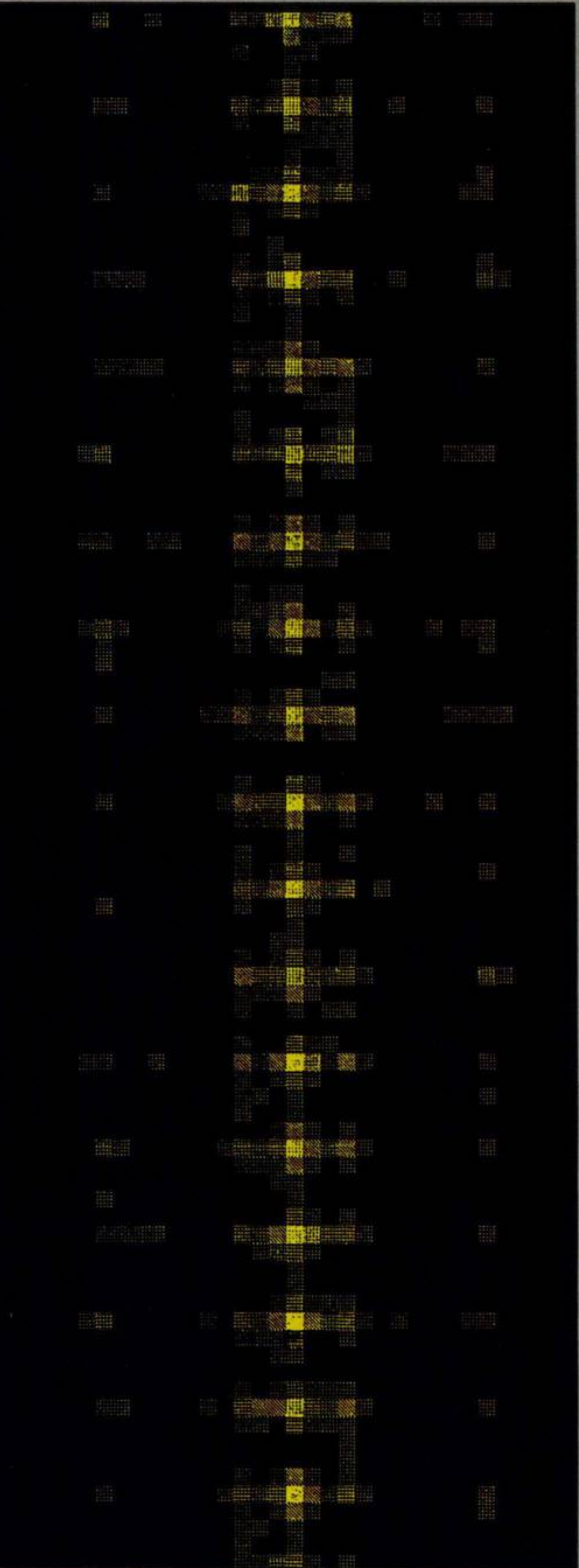
Excited by this coincidence, I wrote a scientific paper about it. But it turned out that other people had done some work on the same subject. In fact, they had even extended the argument. I had nothing new to say about that.

On the other hand, in carrying their argument a step further, they said that it is impossible for neutrinos to be the missing mass material. They argued that all the (by now) slow-moving neutrinos would have fallen into galaxies and been captured. Although galaxies are rather massive, it seems clear that they are not, by themselves, massive enough to provide closure density. There was a contradiction between the requirement that the neutrinos be able to fit close enough together and that they

A Close Look at a Neutrino "Pancake"



The simulated collapse of neutrinos in a supercluster-sized system modeled in two dimensions. The line down the center is a uniform "pancake" of neutrinos.

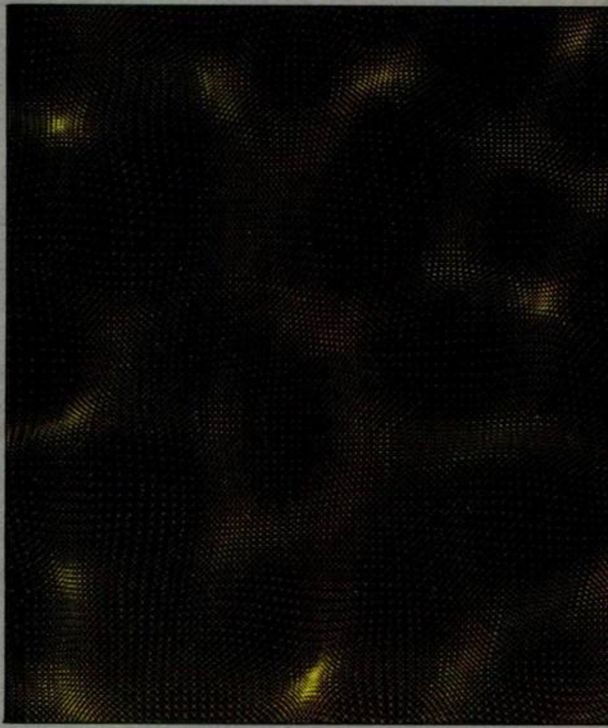


Perturbations of only 1% in the "ordinary" matter density along the "pancake" produce clumps in the neutrino density — our model universe passes a test.

Modeling the Universe

This simulation shows matter collecting into dense regions and "holes" as the model universe expands. In the beginning, which is not shown, the model was almost perfectly uniform. Note that matter first forms a cell-like structure, then flows together into lumps.Such simulations suggest that galaxies may have formed in the"walls," then flowed into clusters. The size of the universe is shown for each frame.

universe ⅛ current size



From Melott 1983, courtesy of Royal Astronomical Society Monthly Notices, © Royal Astronomical Society.

not make the galaxies too massive. It looked as though the idea was done for.

Then a new twist appeared: a number of people realized there would have been "damping" in the early universe. A classic problem in modern cosmology has been to explain both 1) why our universe is so smooth on the very largest scales, with one region looking much like another, and 2) why it is so lumpy on small scales, containing clusters, galaxies, planets, and people.

The leading theory has been based on gravitational instability. It can be shown that if the very early universe was quite smooth, with just slight wiggles, the wiggles would grow. If these wiggles are regions with more matter than average, their expansion is slowed by gravity. The difference between their density and the density of the rest of the universe increases until the expansion in the neighborhood stops and the universe has a lump in it. Meanwhile, the rest of the universe goes on expanding. These lumps could become galaxies.

The problem with neutrinos is that such lumps, or perturbations corresponding to the amount of matter in a galaxy, would have evaporated. Since neutrinos do not collide, they would have flown around freely in the early universe, when they were hot and fast-moving. Neutrinos could easily escape any lumps that might form, smoothing them out — a process called damping. As the universe expands, the neutrinos cool and slow down until they can be captured, so the damping stops. A number of calculations of this process showed that all fluctuations smaller than some tens of megaparsecs across — far larger than galaxies or even clusters of galaxies — would be damped out, leaving the universe no "seed" fluctuations to grow into galaxies.

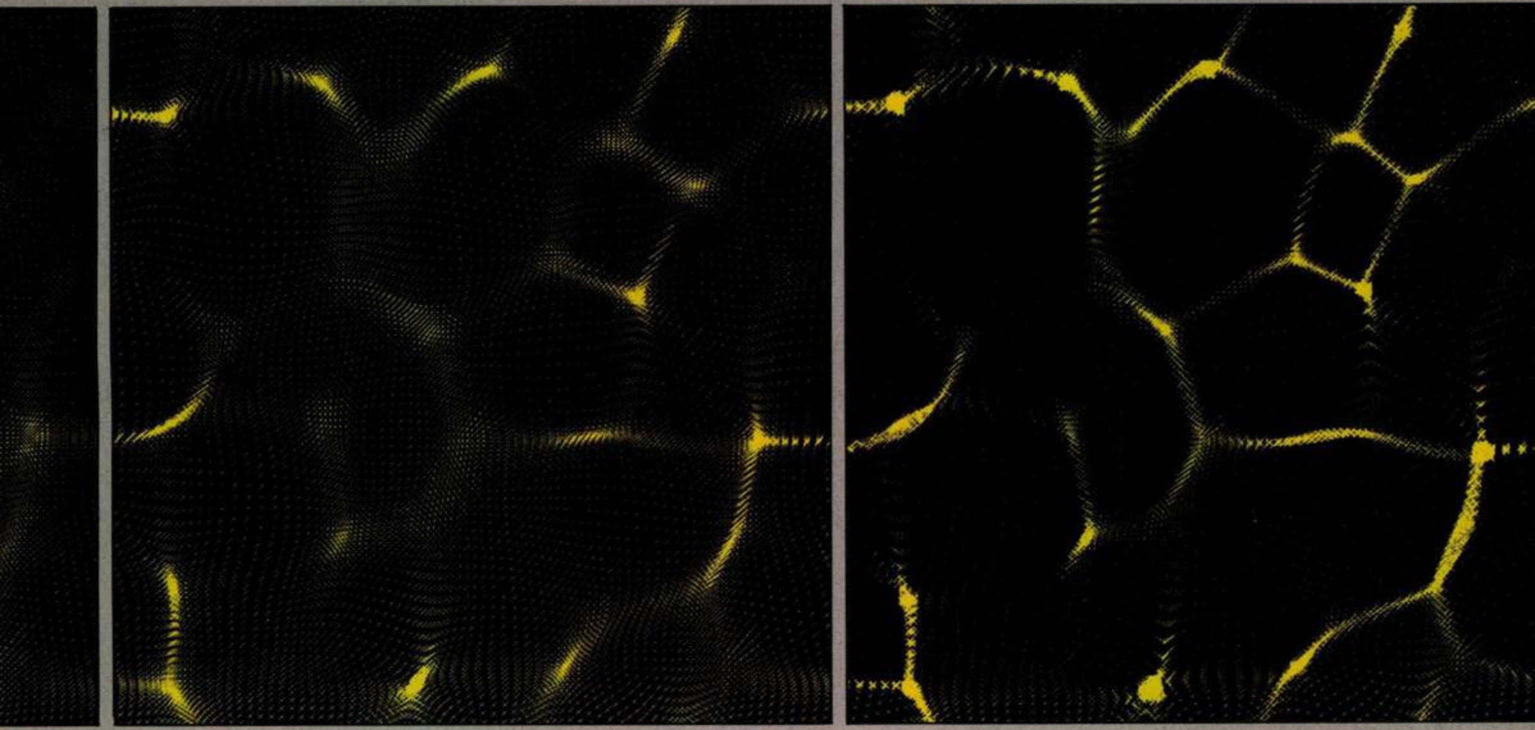
Another difficulty is that when a structure as big as the surviving ones collapses under gravity, the particles come together at velocities around 1,000 kilometers per second. Since neutrinos don't collide, it's hard to imagine how the lump could capture them. A particle going that fast is not captured by the gravity of a galaxy, since a normal galactic escape velocity is about 200 kilometers per second.

Note that there are two arguments here: first, that all the neutrinos would cluster in galaxies and make them too heavy; and second, that none would be able to cluster in galaxies. It seemed to me that a computer calculation — sometimes called a numerical experiment — was called for.

Usually, when scientists calculate things analytically, we have to oversimplify the situation. Analytic calculations are an extension of the algebra problems many of us did in high school. Such problems are always oversimplified; they feature wheels rolling without friction or people working at a precisely constant rate — and we all know the real world has friction, and that people work at varying rates. It is just this sort of complicated situation that can be dealt with much more easily on a computer.

An analytic calculation of gravitational clustering might assume, for example, that the collapsing object was spherical or that the density within it varied in some simple way. In a numerical simulation, we include a number of particles (thousands or even millions), which attract each other by the laws of gravity. We are free to distribute the particles as we see fit, not restricted by analytical simplifications.

For reasons I will describe later, people interested in the theory of galaxy formation believe galaxies collapse in a "pancake" fashion. In gravitational collapse, astrophysicists typically start with a perfectly round (spherically symmetric) gas cloud, with everything falling toward the center. Many analytic conclusions have been based on this model. However, if the object is even slightly flattened, the amount of flattening will increase as it collapses. It is most unlikely that the lumps in the early universe would be so perfectly spherical that they would not "pancake."



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A theory of galaxy formation based on this type of collapse has been developed primarily in the Soviet Union by Ya. B. Zel'dovich and his co-workers. Their idea is that very large structures — structures the size of clusters or superclusters of galaxies — collapse as pancakes; then, after the matter collides in the center, the gas cools and fragments into the progenitors of galaxies. This is different from the theory favored by Western scientists, in which the first lumps to condense are *smaller* than galaxies and later cluster gravitationally to form them.

Since our hypothetical neutrino-dominated universe has all the small-scale perturbations damped out, galaxies must form in a manner similar to that envisioned in the Zel'dovich theory, which we shall call the pancake theory. It is that theory which I have tried to simulate by computations described here.

Due to the flattening effect, the most important effects are likely to be those in the two streams of particles falling more or less toward each other. The first step is to figure out what these effects are. To do this, I decided to have a close look at this sort of collapse. What sort of numerical method to use was the next decision; in this kind of computing there can be many ways to approach the same problem. I won't discuss the details of the method, but will simply mention some of the factors that motivated my decision.

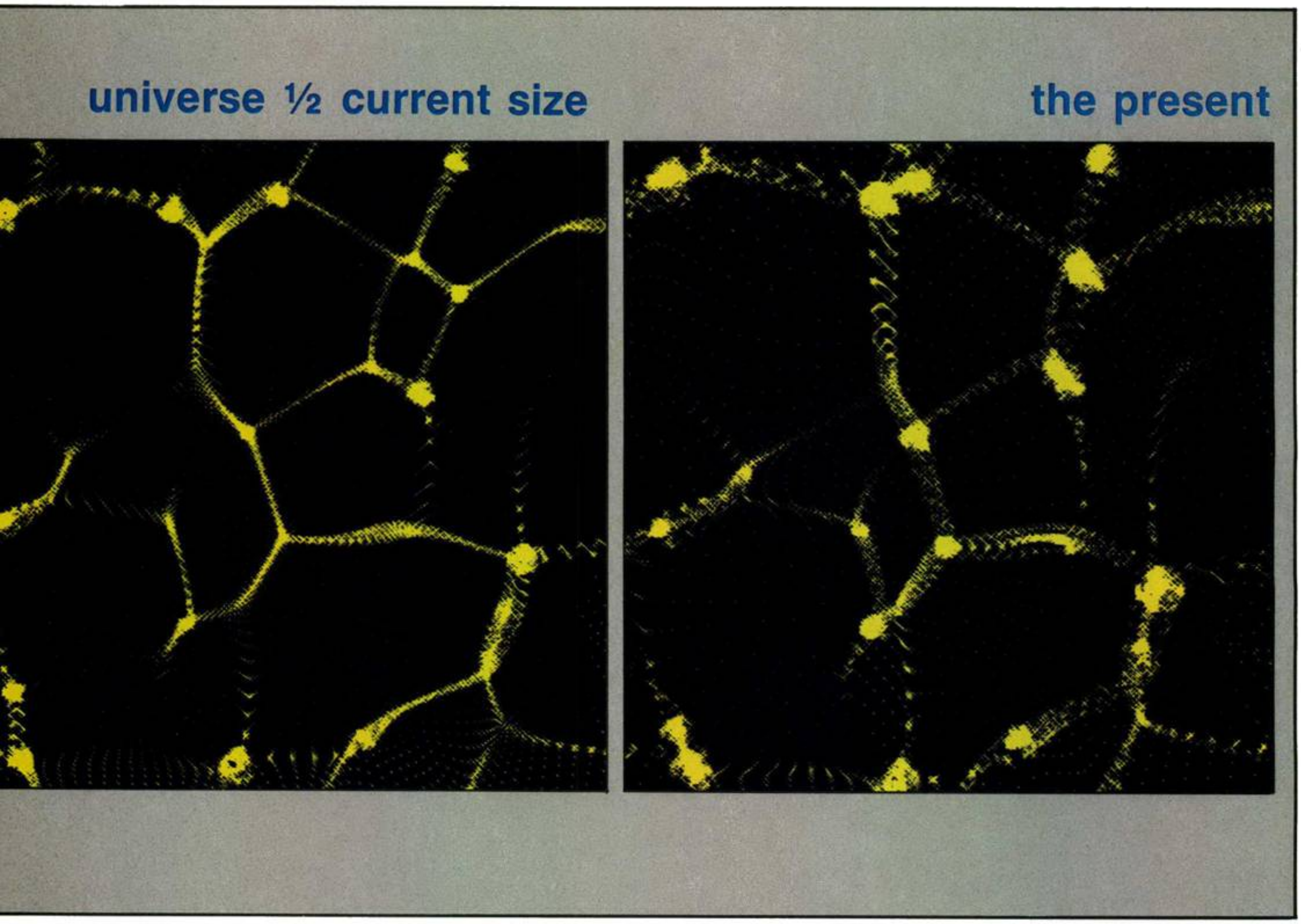
My first reaction was to use a well-tested simulation method that is widely used in astrophysics, called a "direct N-body" method. But this method was developed for studying the clumping of a rather lumpy system composed of stars or galaxies. In our neutrino universe, the lumps shouldn't have formed until after the collapse. That is, we are assuming that all the "structure" forms as a result of the collapse. To test this properly, however, we need a computer program that does not create any lumpiness in its numerical method.

As it happens, plasma physicists have developed methods that are appropriate for this problem. Over the last two decades, they have created a method called the Particle-in-Cell, or PIC, method to model plasmas. A plasma is an ionized gas in which the electrons and atomic nuclei move around more or less freely. Plasma is a "smooth" system — a system in which the force acting on a particle is the collective of the whole system, rather than the nearest neighboring particle. This makes it similar to our smooth, neutrino-dominated universe. Furthermore, the electrical force between two particles is proportional to the inverse square of the distance between them, just as gravitational force is.

Naturally, some mathematical changes are needed to adapt a computer method used in modeling plasmas to modeling gravitational clustering in an expanding Universe. But once these changes are made, the method is essentially the same. In the two years since "The Invisible Universe" appeared in ASTRONOMY, I have been using this method to investigate a number of issues which are important if our universe really is neutrino-dominated.

The first important question seemed to be whether neutrinos could cluster in such a way as to allow the dark halos around the galaxies to form. You remember that the collapse velocities of the large systems were supposedly so high that the neutrinos could never be captured by the relatively weak gravitational fields of galaxies.

To begin to answer the question, I decided to watch the simulated collapse of a supercluster-sized system. I used a one-dimensional computer code for this problem. This means there is only one "direction" in the problem. In this case, it is the direction perpendicular to the collapse, an approximation of the highly flattened pancake-style collapse. By using this approximation, I was able to gain high resolution, that is, I was able to follow the collapse to distances that were a small fraction



universe ½ current size

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of the size of the whole system. The cell size used in the computer simulation must not blur out the very objects we have an interest in — galaxies.

I studied the collapse of a perturbation starting with the time when it was just a small "wiggle" in the density of the matter on an otherwise uniform background. At first, the extra gravity in the bump caused this part of the universe to expand only a bit more slowly than the rest. But its growth caused it to be denser still, compared to the background, than it was before. This caused still more growth in the bump and more gravitational attraction. This runaway effect is the well-known gravitational instability.

Eventually, the region of the bump actually stops expanding and begins to fall back on itself. It can now be thought of as a partially isolated system, since it has decoupled from the overall expansion of the universe. The matter falls inward toward the center, compressing the gas there.

This simulation is meant to study the collapse of neutrinos. Since neutrinos do not collide, the streams fly through each other, but the small fraction of matter we assume to be normal would collide as before. It is, however, a very complicated problem to tackle the behavior of this gas in detail, and this is only now being done. Since in this theory most of the gravity would come from the neutrinos, I ignored the gas temporarily.

I found that after the collapse, the average speed of the particles was very high — too high to allow them to form into galaxies. But this was not the whole story: a condensation remained in the central plane. A substantial fraction of the particles now lay in this region and had velocities low enough to form galaxies.

So the numerical experiment avoided the two objections — that all or none of the neutrinos would end up bound to galaxies — by demonstrating that a specific fraction would be. This is the power of computer modeling of physical systems. It follows the physics in detail, often clarifying ideas based on general physical principles. In this case, an answer better for the prospects of the neutrino-dominated universe theory cannot be imagined.

Each problem solved presents new problems. We have the neutrinos in a reasonably thin layer, a sheetlike "wall" between valleys. Galaxies are individual objects. Somehow the neutrinos in the "wall" must clump around individual objects. Another numerical experiment was needed, so again I decided to take the most straightforward hypothesis and see if gravity could do the job.

A two-dimensional program was the minimum needed for this approach since the neutrino pancake would fragment in a direction perpendicular to the direction of the collapse that formed it. Again, I used the "planar collapse approximation" — but this time I allowed the particles to move in a direction perpendicular to the collapse.

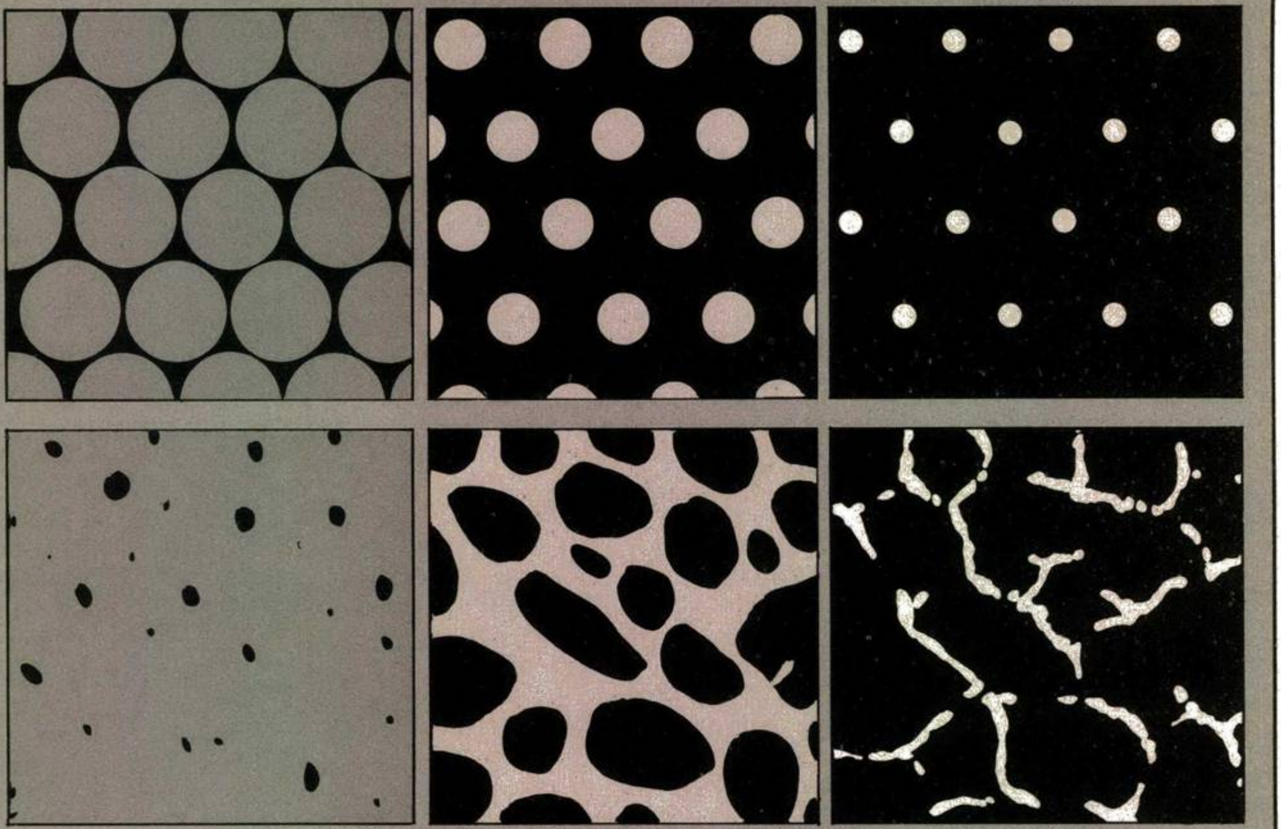
Of course, the only sidewise motion they had in the pure-planar collapse was thermal motion. You can see the result of collapse in the computer output — the darkness of the squares is proportional to their mass density. The dark central layer is the condensation I mentioned earlier. Can this layer fragment?

I decided to test whether clumping ordinary matter could set off clumping in the neutrinos. I put in "bumps" representing ordinary matter along the central plane at the moment of pancaking. Even when only one percent of the total mass was assumed to be in these bumps, I found that it was enough to set off fragmentation in the neutrinos. The uniform layer has fractured — and our model universe passes another test.

One might rightly point out that I had to put in the bumps by hand. In a real universe, where would they come from? After all, our universe is supposed to be smooth on this size scale.

There are two possibilities. One is that there were also

Two Views of Collapse



Numerical simulation reveals a new picture of the universe. Analytical models (upper row) have assumed that independent blobs of matter collapse spherically, but numerical models (lower row) suggest that matter collapses first into "walls" separating "holes," then into "lumps."

perturbations in the density of ordinary matter that had not been important until this phase. Another is based on the behavior of gas at certain temperatures — dense, cool clouds can develop from a tenuous, hot medium. They can grow very fast and might provide the needed lumps — in fact, early results from some computations that include gas cooling suggest this may be possible.

We have been gradually expanding our field of view, including more and more effects. This procedure is inherently risky: I might have uncovered something at some stage that made earlier work inappropriate or even silly. Luckily, this hasn't happened.

At this stage, we've looked only at cross sections of isolated pancakes. In the real universe, nothing is truly isolated, so as our next step, we have to drop this approximation. This is important because it had been argued that when the effects of interactions were included, the structures would fragment *before* the collapse was complete.

These comments were based on a combination of theoretical considerations and visual inspection of computer simulations done by Soviet cosmologists using a method similar to mine. After seeing the Soviet results, I decided to try using their method. I found that there is a "phony clumping" which takes place when too few particles are used in a simulation. In studying the interactive effects, the Soviets had used about 4,000 particles. I used about 90,000 and did not have this sort of clumping. An independent check showed that the theoretical arguments were wrong. Here we see a complex intertwining of theory and numerical experiment, not unusual in modern physics.

Let's have a look at some of these simulations. There is no point in looking at the beginning, when the universe was $\frac{1}{1000}$ its present size, because the picture is uniform and uninteresting. In looking at two-dimensional simulations, we see the universe ⅙, ⅕, ⅓, ½, and 1 times its present size. I had put down many perturbations in different directions at the beginning. You can see that when the first collapse happens, things are very flat.

This reinforces the idea that flatness is important. In fact, it is even more important than we indicated earlier. Our first simulation included only a single overdense region, but if perturbations filled the early universe, all the "hills" would have "valleys" between them. The absence of matter between the hills is also important, and the lack of gravitational force from them would have made things go flat even more totally than we would have thought.

It is as if "holes repel" in the sense that matter attracts. The scale shown in the simulations expands along with the universe. Since a region of less-than-average density slows the expansion less than it should, the fraction of the universe the hole occupies grows.

So instead of watching matter falling into little round lumps, we see holes growing until they collide and squash matter between them. The matter flows along the walls to lumps where they join. Look at the simulation in this way — you'll see another surprise lurking there. People often assume that in the adiabatic theory galaxies form inside clusters. But these pictures suggest it is entirely possible that galaxies formed in the walls, between holes, and then flowed into clusters. Many points depend on this question of the geometry of the system of hills and valleys.

The second half of "Cosmology on a Computer," our Stellar Frontiers for July, contains Melott's three-dimensional simulations of the early universe.

Adrian Melott is a researcher in cosmology and astrophysics at the University of Pittsburgh. His primary research interest has been the computer modelling described in this article. As this issue goes to press, he is in Moscow studying galaxy formation with Soviet cosmologists.

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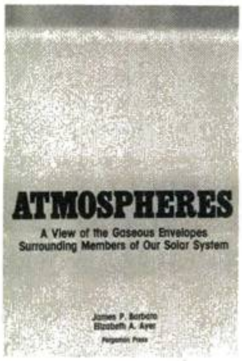
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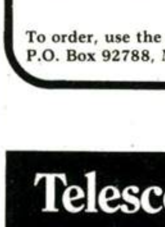

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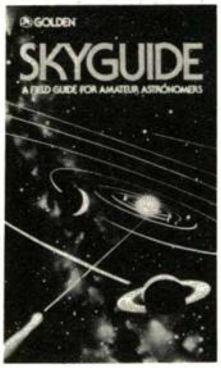
FOR SALE — *Sky & Telescope* back issues, April 1972 through December 1982, $200. *Scientific American*, most issues 1974 through 1978 plus some earlier, $40 plus postage. Contact Dennis Held, 202 W. Avondale, Champaign, IL 61820. Phone (217) 352-0640.

FOR SALE — 3-inch 80mm f/15 refracting telescope. Five eyepieces, tripod, slow-motion controls, etc. Mint condition. $395, you pay shipping. Contact G. Zeller, 109 Manor Ave., Baltimore, MD 21206. Phone (301) 665-6797.

FOR SALE — Edmund 6" f/6 reflector with mount. Clock drive inoperative, with 28mm RKE eyepiece, $200. Complete set of RKE eyepieces — 28mm, 21mm, 15mm, 12mm, 9mm and 2.5 Barlow — $125. Contact T.G. Schwermer, 2529 Westview, Bartlesville, OK 74003.

WANTED — Members: I'm hoping to start an astronomy club or science club. If you're interested in astronomy, science, and science fiction, contact Mark Gentile, 35 Fairmont Ave., Braintree, MA 02184.



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FOR SALE — Volume 1, numbers 1 through 8 of the *Planetary Report*, the publication of the Planetary Society. Will sell for $200. Contact Brian Neiss, Box 97, Balta, ND 58313. Phone (701) 542-3284.

FOR SALE — Edmund Scientific 6" f/6 with Meade focuser, equatorial fork mount with motorized slow motion declination. In very good condition, with original shipping cartons, $300. 6" f/5 with Meade optics and spider, University primary mirror mount; it has camera platform but would need a focuser for visual use. Fits the mount mentioned above. Will sell separately, $150. Contact Arni Pedersen, P.O. Box 22, Highlands, NJ 07732. Phone (201) 872-0710.

FOR SALE — ASTRONOMY back issues, October 1977 through September 1982, condition good to excellent. Also three binders, $80 or best offer, plus shipping. *Star & Sky*, October 1979 through February 1981, condition excellent, $20. Contact Tom Tauber, 1206 Curtiss, Ames, IA 50010. Phone (515) 232-3433.

FOR SALE — Edmund 8" f/5 telescope in heavy-duty equatorial mount with clock drive, 6" circles, one 20mm Erfle eyepiece, and 2.5x Barlow, $600. Contact James A. Sego, 24 S. West St., Bargersville, IN 46106. Phone (317) 422-5497.

FOR SALE — Two 6" Meade model 628 reflectors. One new (still in box), one slightly used. $395 and $345, respectively. Located in the Pocono Mountains. You pick up or pay shipping. Contact M. Reinhart, Star Rt. 1, Brodheadsville, PA 18322. Phone (717) 992-7638.

FOR SALE — Meade Model 1020 system 1000mm telephoto lens. In excellent condition, purchased August 1982, used twice. Includes high-transmission coating on correcting lens, T-adapter, dust covers, carrying case, instruction manual. Tele-extender free. Contact Kevin Pichon, 10702 6th Ave., Inglewood, CA 90303. Phone (213) 418-1047.

WANTED — Tax-deductible donation or endowment of a medium-aperture reflector and drive suitable for astrophotography. We are a private, Christian high school and wish to expand our science curriculum to include a formal astronomy program. Contact Robert Courter, Director of Development, Centre County Christian Academy, P.O. Box 47, Bellefonte, PA 16823. Phone (814) 355-7805.

WANTED — Original or photocopy of *Aerophile* magazine, specifically the article on the X-series aircraft; also, technical data on these aircraft. Contact Russ Tobias, 5028 Gregory Court, Santa Rosa, CA 95405.

WANTED — Correspondence with professional astronomer. I am in the fourth year of high school and planning to spend my college years in the United States studying astronomy. Contact Rudolfo-Luigi Morosi, #93 Matalava Center, Lingayen, Pangasinan, Philippines 0702.

WANTED — Accustar, complete with book and overlay, in good condition. Contact Dave Howard, 13413 E. Ave. D-8, Lancaster, CA 93535.

WANTED — Small quantity of mylar for Sahula system. Specification 0.00035". Contact H.M. Coleman, Box 789, Southampton, Ontario N0H 2L0, Canada.

WANTED — 90 mm or 102 mm refractor lens, f/10 to f/15. Will consider any condition, including unfinished Remer kits. State price. Contact M. Schott, 4006 Riverview Dr., Wausau, WI 54401.

WANTED — Collector wants to purchase any material on Shuttle missions, including photographs, magazines, films. Contact Stewart Reid, 43 Christie Place, Bishopmill, Elgin, Scotland.

WANTED — Information and advice for a 16-year-old who is seeking a career in space exploration, astronautics, or a similar field in astronomy. All challenging opportunities are welcome. Contact: Kevin Jeansonne, Rt. 1, Box 232, Dry Prong, LA 71423.

WANTED — Iowa astronomers. We are compiling a list of permanent observatories within Iowa. Educators or amateurs are asked to contact us to be included in the survey. Contact Larry Kelsey, Earth Science Dept., University of Northern Iowa, Cedar Falls, IA 50614.

WANTED — Amateurs interested in forming an association for research, visual, astrophotography, photometry, telescope making, and Christian fellowship. ''The heavens proclaim the glory of God.'' Donations of old, used equipment, magazines, books, etc., welcomed and appreciated. Contact Fortunato Comunale, 383 Birch Hollow Dr., Shirley, NY 11967.

WANTED — Celestron 5, used but in good condition. Prefer a model that accepts 1¼-inch eyepieces. Contact Robert S. Schriebman, 21515 Hawthorne Blvd., Suite 1260, Torrance, CA 90503. Phone (213) 540-2363.

WANTED — Observers of the date of Venus dichotomy (when Venus is 50% sunlit), from all over North America, to prove or disprove the Schroeter effect (a loss of brightness near the terminator line). I need the following information: your date for the dichotomy; whether obtained by direct observation or interpolation; size and power of telescope used; filter used; name and location of observer. Please send it to Mark A. Gelinas, 1362 Holmes, St-Hubert, Quebec, Canada J4T 1P5.

WANTED — Information on how to buy a ''Goodbye Saturn, Hello Uranus'' button, as worn by Voyager crew. Contact John Pellack, 2433 Fitzgerald St., Philadelphia, PA 19145.

WANTED — Information on how to photograph Space Shuttle launches. What kind of film, equipment, and exposures should be used? Please contact asap (Mrs.) Margaret S. Michael, 222 Orchard Dr., Apt. 11, Whitehall, PA 18052.

WANTED — Looking for a 6" or 5" telescope lens or assembly, any focal length, reasonably priced. Contact Maral Sofion, 1260 So. Minnewawa, Fresno, CA 93727.

WANTED — ASTRONOMY back issues from January 1974 through December 1974 inclusive, in excellent condition. Please state price. Contact Michael Keylin, 4600 9th Ave., #602, Brooklyn, NY 11220. Phone (212) 633-5871. (No collect calls, please.)

WANTED — Correspondence with any professional astronomer. I am 16 and interested in becoming a professional astronomer. Any information regarding universities, reading materials, job prospects would be appreciated. Contact Sean Conway, 242 Walnut St., Waterbury, CT 06704.

WANTED — ASTRONOMY back issues, Vol. 1, nos. 3-5 (October to December), 1973. Send to Jessie Ball duPont Library, Serials Dept., University of the South, Sewanee, TN 37375.

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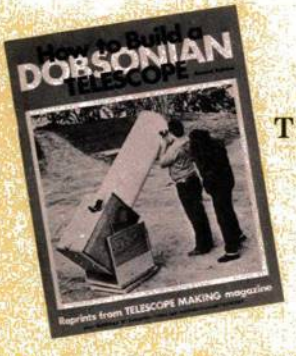

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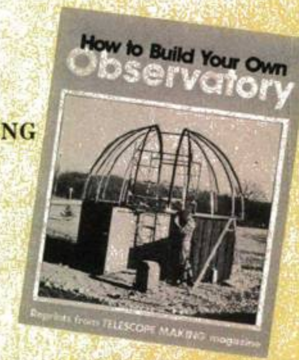

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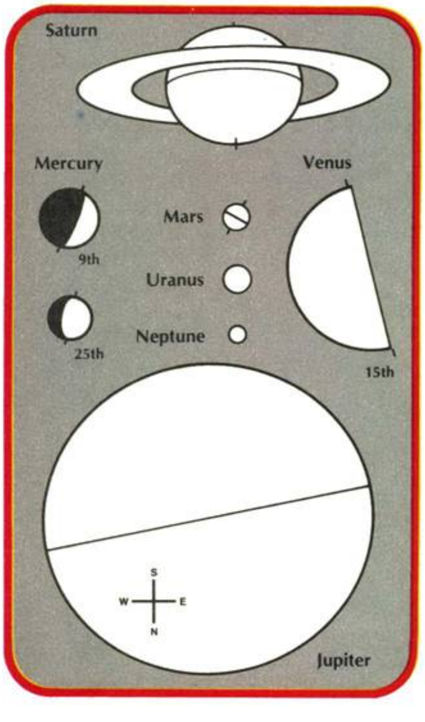
the backyard astronomer

close-up on bootes

Mercury

By the first of June, Mercury can be glimpsed very low in the east-northeastern sky just before sunrise. On the 8th, 45 minutes before sunrise, it will be at greatest western elongation (23°) from the Sun at an elevation of 3.3° in azimuth 73°. It will hold essentially the same elevation from then until the third week of June, when it will begin to sink lower and lower, finally vanishing into the blaze of sunlight by the end of the month. Because of its low altitude, this apparition of Mercury would be among the year's least interesting — except for what happens on the 9th, the day after greatest elongation.



On this date, for observers located from approximately Virginia northward through the eastern states of the U.S. up to and including the Canadian maritime provinces, Quebec, and Ontario, there will be an occultation of Mercury by the Moon. The event takes place just before or soon after local sunrise, depending on your location. Only the easternmost locations will see the disappearance of Mercury behind the Moon's bright limb (around 8:30 UT); the rest will see the reappearance sometime after 9:15 UT.

By the time the Moon rises for observers farther west across the continent, it will have moved more and more to the east of Mercury, but the two objects will still present a fine sight when paired together in a low-power eyepiece. The Moon's age will be 27.6 days, and it will display a disk only 4% lit. Mercury will be about 39% lit and will have a disk 8" of arc across; it will shine at +0.7 magnitude.

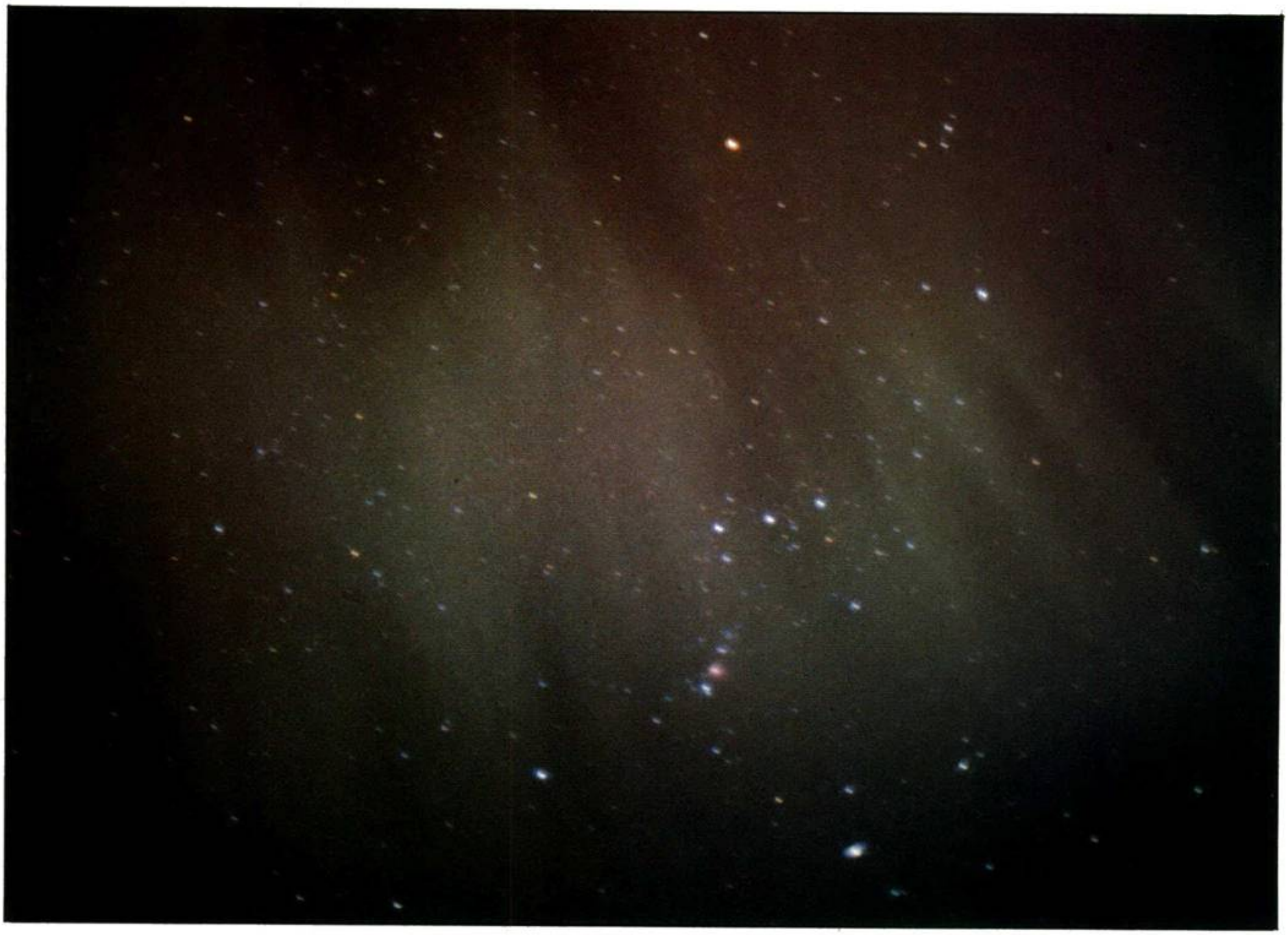
Venus

Venus also reaches its greatest elongation (45.5°) from the Sun this month, but the direction is eastern. A highly prominent object in the west as the sky deepens into twilight, Venus has lost a little of its elevation since its peak last month. The planet's disk is half lit on the 16th, the date of greatest elongation, and its apparent diameter is 23" of arc.

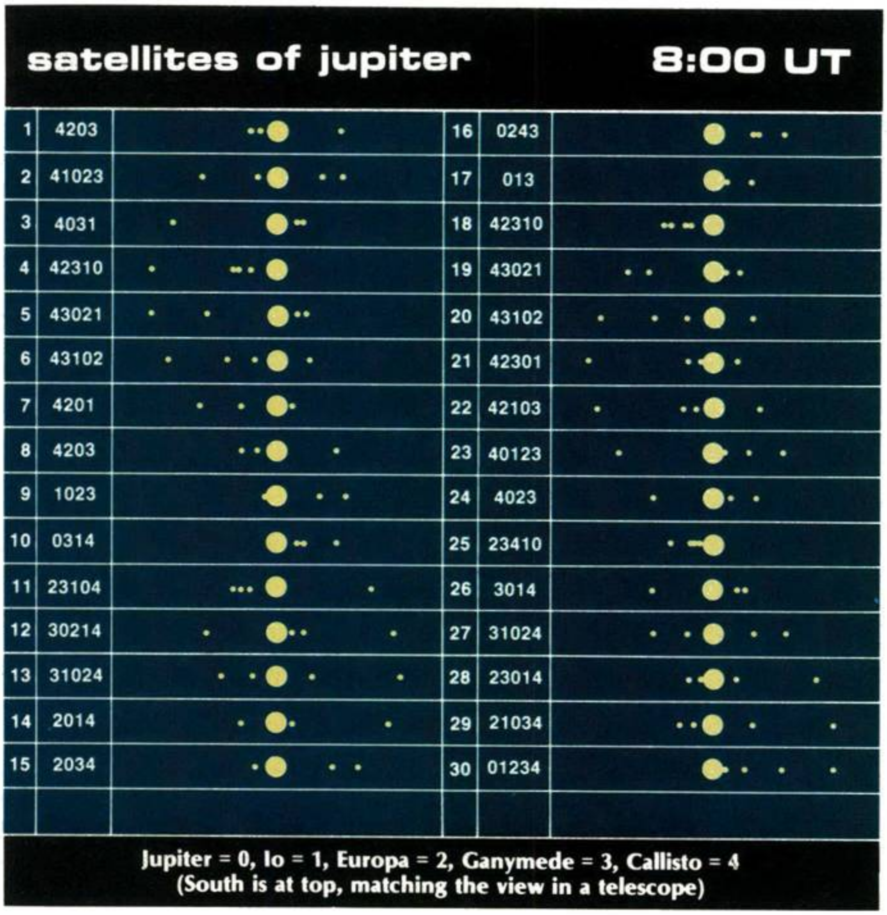
During June and July, you'll see it drop more and more swiftly toward the western horizon, brightening steadily from its June 1st magnitude of −3.8 to its point of greatest brilliancy on July 18th, when it will be at −4.2 magnitude. Although changes in the planet's illuminated disk and apparent brightness aren't much from one day to the next, you'll notice them over the course of a week's telescopic observations.

A 2.8-day-old Moon, 11% illuminated, will lie to the lower right of Venus after sunset on the 13th; during the daylight

The North America Nebula is a prominent diffuse cloud of gas in Cygnus; its companion to the right is the Pelican Nebula. Ron Potter's photo, June's "Best Astro-Photo" award winner, was taken using an 8-inch Schmidt camera and gas-hypered 2415 film (plus a #92 filter) with a 15-minute exposure at f/1.5.



On January 9, 1983, Alan French of Schenectedy, New York, photographed this bright streaky aurora superimposed on a setting Orion. His equipment was simple — he placed his 35mm camera with its 50mm normal lens set to f/1.4 on a tripod and made a 30-second exposure on 400 ASA slide film.



satellites of jupiter **8:00 UT**

1	4203	16	0243
2	41023	17	013
3	4031	18	42310
4	42310	19	43021
5	43021	20	43102
6	43102	21	42301
7	4201	22	42103
8	4203	23	40123
9	1023	24	4023
10	0314	25	23410
11	23104	26	3014
12	30214	27	31024
13	31024	28	23014
14	2014	29	21034
15	2034	30	01234

Jupiter = 0, Io = 1, Europa = 2, Ganymede = 3, Callisto = 4
(South is at top, matching the view in a telescope)

hours on the 14th, the Moon will pass just south of the planet, and by nightfall on the 14th, it will have moved on to the upper left of Venus. Good viewing and "pretty-picture" material!

Earth

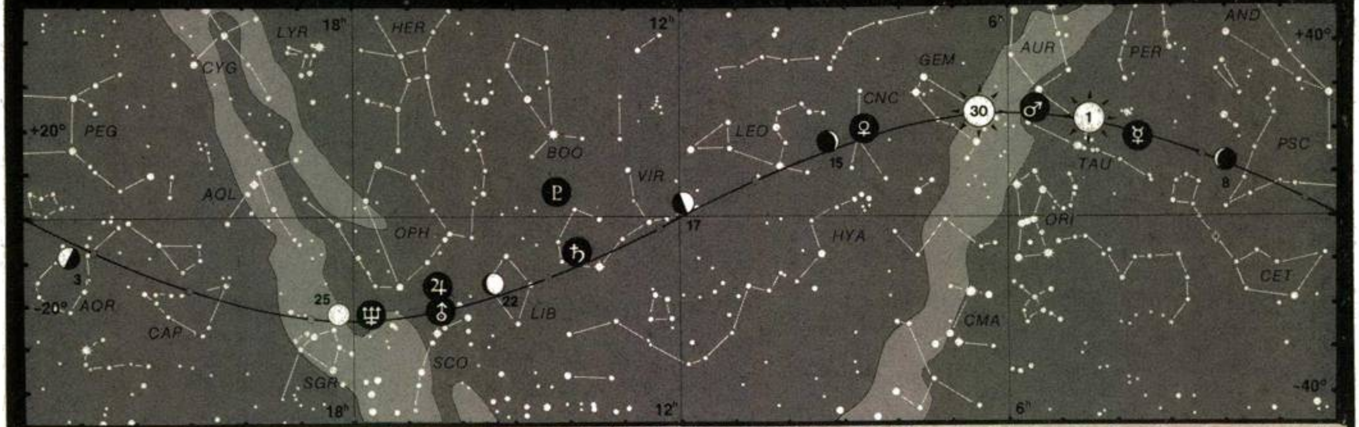
The Sun will reach its farthest northern declination at 23:09 UT on the 21st of June. This is the Northern Hemisphere's summer solstice, the Southern Hemisphere's winter solstice.

Moon

June has two eclipses in store, only one of which is visible from the Western Hemisphere. On June 25th, between 5:25 UT and 11:02 UT, there will be a partial eclipse of the Moon. At maximum eclipse, the northern 34% of the Moon's disk will be covered by the Earth's umbra. The sequence of events is listed in the box on page 80. Except for the extreme northeastern parts of the continent, the entire event will be seen before moonset.

The other — a total solar eclipse with a maximum duration of 5 minutes 11 seconds — occurs two weeks earlier and

planetary data june 1983


LYR
18h
HER
12h
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AND
+40°
CYG
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BOO
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VIR
8
17
ORI
OPH
HYA
3
CET
25
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-20°
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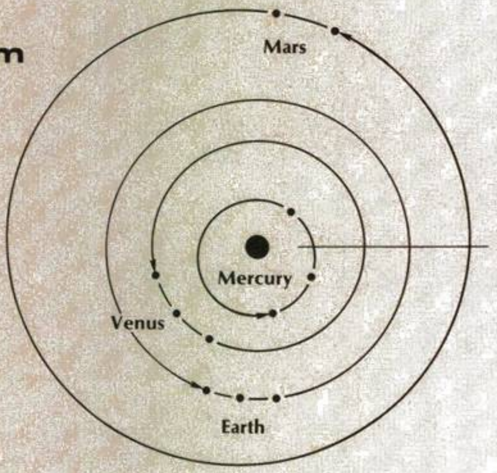
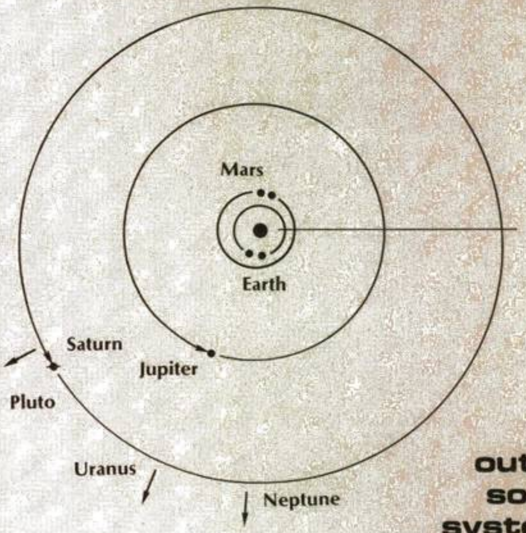
CMA
CAP
SCO
SGR
-40°
18h
12h
6h

inner solar system


Mars
Mercury
Venus
Earth


Mars
Earth
Saturn
Jupiter
Pluto
Uranus
Neptune

outer solar system

		Date	Mag.	Angular Size	% Illum.	Distance (AU) from: Earth	Sun	Longitude: Heliocentric	Ecliptic	R.A. (1983.5)	Dec.
Sun		1	−26.7	31.6′	—	1.01	—	—	69°57.9′	4h 33.2m	+21°56.7′
		15	−26.7	31.5′	—	1.02	—	—	83°21.7′	5h 31.0m	+23°16.5′
		30	−26.7	31.5′	—	1.02	—	—	97°40.3′	6h 33.4m	+23°13.2′
Mercury	☿	1	+1.2	9.6″	24%	0.70	0.45	285°26.8′	47°39.6′	3h 06.4m	+13°31.4′
		15	+0.2	7.0″	52%	0.95	0.39	332°25.7′	60°24.6′	3h 57.3m	+17°36.0′
		30	−1.2	5.4″	89%	1.24	0.31	46°46.8′	85°50.4′	5h 43.8m	+23°20.7′
Venus	♀	10	−3.9	22.2″	53%	0.76	0.72	210°28.5′	123°15.0′	8h 26.7m	+21°34.4′
		30	−4.1	28.2″	41%	0.60	0.73	226°30.1′	141°37.9′	9h 39.8m	+15°03.1′
Mars	♂	15	+1.7	3.4″	100%	2.55	1.54	78°16.4′	79°49.6′	5h 17.5m	+23°37.3′
Jupiter	♃	15	−2.1	45.0″	100%	4.38	5.35	247°28.8′	243°22.4′	16h 08.0m	−20°04.2′
Saturn	♄	15	+0.7	18.2″	100%	9.17	9.78	212°51.3′	207°28.8′	13h 47.6m	−8°17.9′
Uranus	⛢	15	+5.8	3.8″	100%	17.98	18.95	247°18.9′	246°00.6′	16h 18.3m	−21°17.4′
Neptune	♆	15	+7.7	2.5″	100%	29.25	30.27	267°49.9′	267°30.7′	17h 51.3m	−22°09.5′
Pluto	♇	15	+13.7	0.1″	100%	29.78	29.88	208°33.3′	206°29.2′	14h 03.6m	+5°34.9′

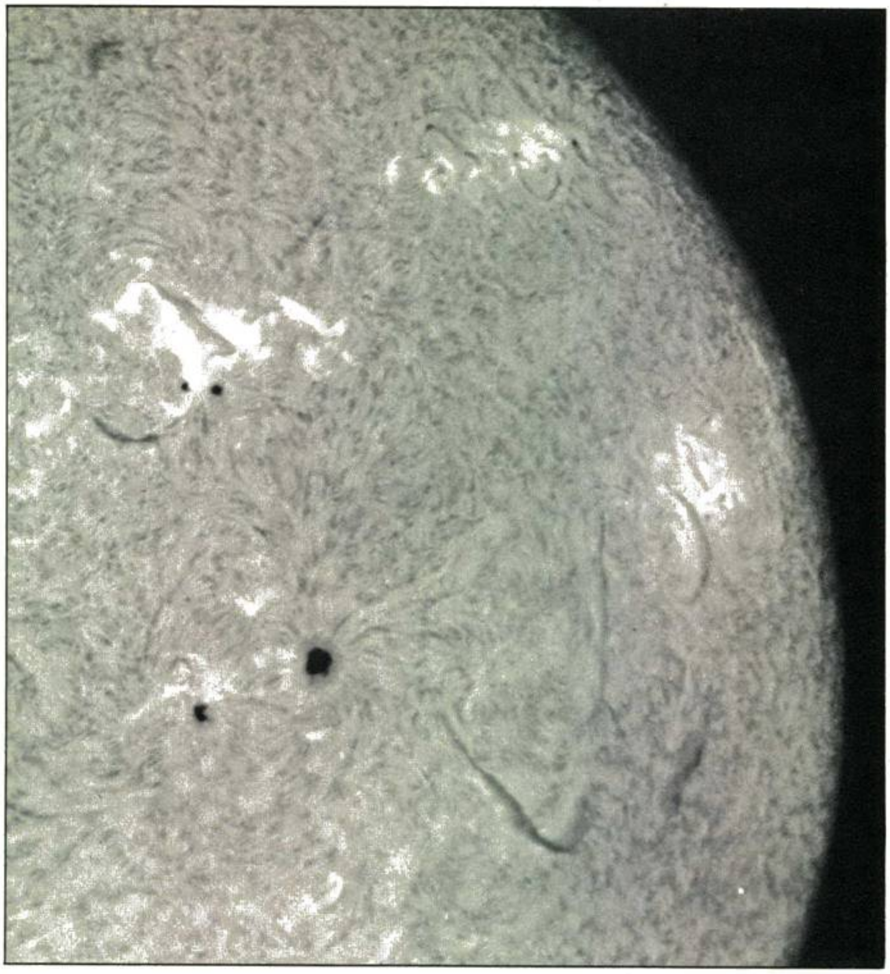
moon data

Last Quarter	June 3 at 21:07
New Moon	June 11 at 4:37
First Quarter	June 17 at 19:46
Full Moon	June 25 at 8:32
Last Quarter	July 3 at 12:12
Apogee: June 1 at 8h	404,717 km.
Perigee: June 13 at 6h	362,550 km.
Apogee: June 28 at 23h	405,650 km.

universal time

Astronomers the world over use an unambiguous system of time reckoning — Universal Time (UT) — based on a 24 hour clock. Times given in The Backyard Astronomer are UT unless noted otherwise. To convert UT into your local daylight time, subtract the following number of hours for each time zone: EDT, 4; CDT, 5: MDT, 6; PDT, 7; Alaska, 9. For example, if an event is to happen at 03:00 hours UT on June 7, then EDT for the event is 11 p.m., June 6. Likewise, 03:00 UT on September 2 becomes, in PDT, 8 p.m., September 1.

half a world away. On June 11th, the shadow of the Moon will touch the Earth's surface in the Indian Ocean to the southeast of Madagascar and then travel northeastward toward Java. It will reach its farthest northern point near longitude 120° E, latitude 5° S in the archipelago between Borneo and New Guinea. Thereafter the path of totality will curve and run southeastward, broadly paralleling the northern coast of Australia. It will leave the Earth in the South Pacific near longitude 170° E, latitude 18° S.



Above: The Sun in Hα, photographed on October 29, 1982, by Edwin Hirsch. Right: Clive Gibbons photographed a young Moon, showing the region to the north of Mare Crisium. The crater with low relief in the center is Messala. He used an 8-inch SCT and a 1-second exposure at f/70 on 400 ASA film pushed to 800 ASA.

Mars

The Red Planet is in conjunction with the Sun on June 3rd at 11h UT; it will be out of sight all month.

Asteroids

Ceres (magnitude 8.1) is in the southwestern corner of Aquarius, near the borders of Capricornus and Piscis Australis. Its positions:

10th: 22h 14m 09s, −21° 15.6′
20th: 22h 17m 08s, −21° 50.3′

Ceres rises a little after 1 a.m. local daylight time in mid-June.

Pallas (9.5) is moving northward across the western end of Sagitta toward Vulpecula. Its positions:

10th: 19h 11m 47s, +22° 22.8′
20th: 19h 02m 40s, +22° 47.1′

Pallas rises around 7 p.m. local daylight time on the 15th.

Juno (9.9) is moving eastward through south-central Pisces. Its positions:

10th: 0h 33m 28s, +4° 50.4′
20th: 0h 49m 17s, +5° 52.1′

Juno rises a little before 2 a.m. local daylight time at mid-month.

Vesta (8.4) has a path that is taking it across the southeastern corner of Aries into Taurus, where it will be about 10° south of the Pleaides late in June. Its positions:

10th: 3h 13m 42s, +12° 53.0′
20th: 3h 30m 27s, +13° 56.7′

Vesta rises a little after 4 a.m. local daylight time on the 15th.

To facilitate plotting their positions on a star atlas, all asteroid coordinates are for the epoch 2000.0.

Jupiter

Now past opposition, Jupiter rises before sunset and, by the time twilight has faded to full darkness, will be well above the horizon in the southeast. Its retrograde course is taking it away from Uranus and toward the double star Beta (β) Scorpii. It will pass 10′ of arc south of Beta at 23:34 UT on the 22nd. The star's two spectral type-B components are of magnitudes 2.6 and 4.9 and are separated by 14″ of arc in position angle 23° (measuring from the primary).

Saturn

During June, Saturn is nearly at the western end of its retrograde loop and remains all month about 6° to the northeast of first-magnitude Spica. Currently, the northern side of the rings is tipped 14.7° to our line of sight and 16.6° to the Sun.

The Moon will pass 3° north of Saturn at 3h UT on the 20th.

Uranus

Uranus lies a short scan eastward from Jupiter at a declination of about a degree lower. Its location is also about 2° north of the sixth-magnitude globular star cluster M-4. Uranus has a disk 3.8″ across and shines at 5.8 magnitude.

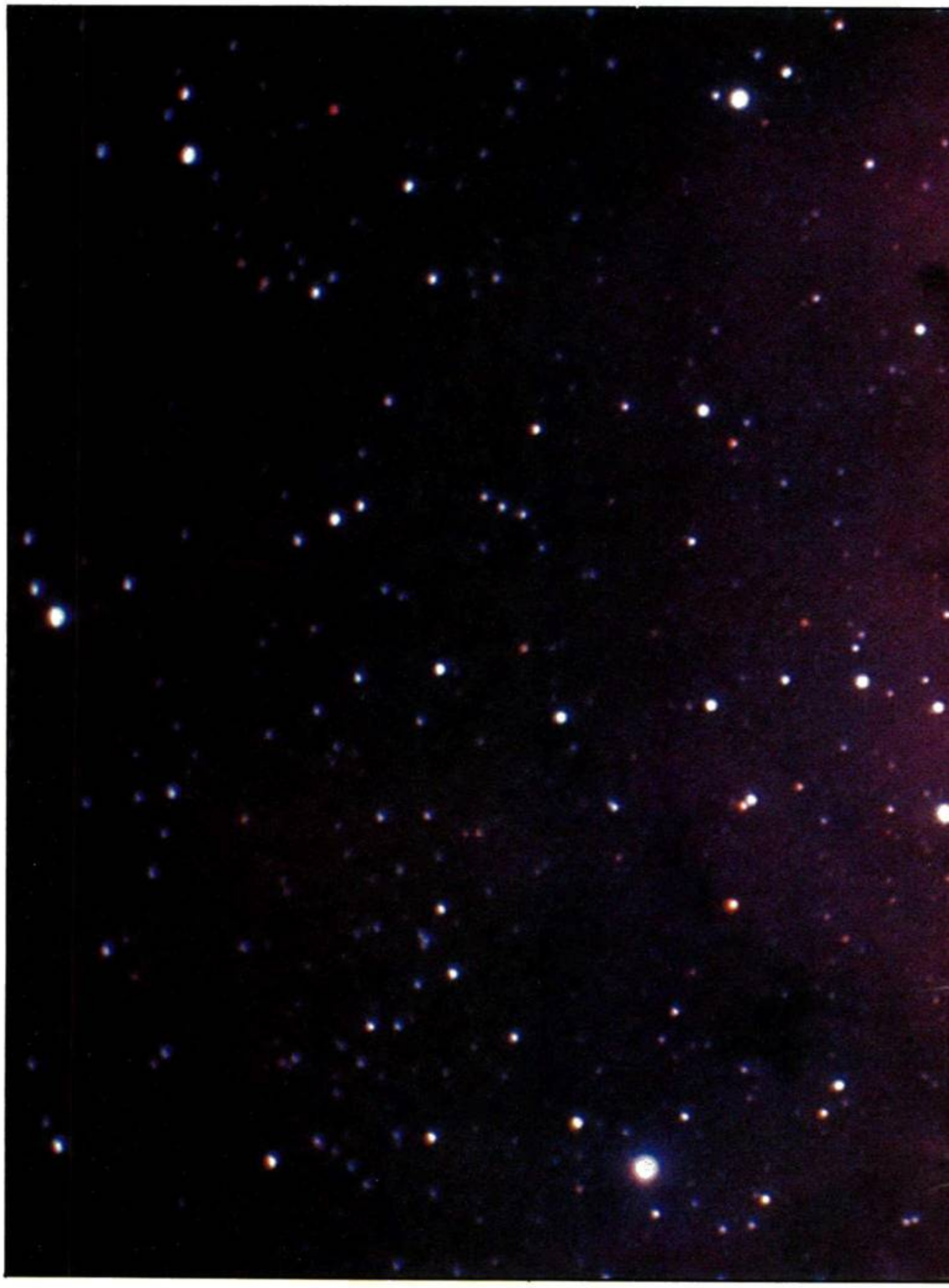
Neptune

M-20, the Trifid Nebula, remains your best (and prettiest!) guidepost for locating Neptune. Find the nebula with a low-power eyepiece, then scan a degree north and about 10 minutes of right ascension westward. You've found the planet when you spy its 7.7 magnitude, 2.5″ of arc disk (you'll need a medium-power eyepiece to confirm it). Neptune is at opposition to the Sun on June 19th at 17h UT.

the partial lunar eclipse, June 25th

	UT	EDT	CDT	MDT	PDT
Moon enters penumbra	5:43	1:43	0:43	**11:43**	**10:43**
Moon enters umbra	7:14	3:14	2:14	1:14	0:14
Mid-eclipse	8:22	4:22	3:22	2:22	1:11
Moon leaves umbra	9:30	5:30	4:30	3:30	2:30
Moon leaves penumbra	11:02	7:02	6:02	5:02	4:02

At maximum eclipse, 34% of the Moon will be immersed in the umbra; boldface times are p.m. on June 24th.



The gas in the central regions of the Lagoon Nebula (M-8) glows red amidst the bright young stars of the nebula. This object crosses the meridian at 12:30 a.m. local daylight time on June 15th. John Gleason's photograph was taken with an 11-inch SCT, using a 45-minute exposure at f/10 on 400 ASA film.

Meteors

Though June has no strong annually recurring shower, it does have a minor display worth looking for. Known as the June Lyrids, their radiant lies in the same constellation as the better-known Lyrid shower that occurs in April, but a little farther to the east. The shower is certainly sparse — some 10 per hour at best — but the Moon will be out of the way on the night of peak activity, June 15th/16th. Since the display will be at its best, give it a try.

close-up on bootes

June is a transitional month for deep-sky observers: the summer observing season begins, offering a bright selection of Milky Way objects, but the region of sky away from our Galaxy — the broad area that contains lots of external galaxies — can still be observed. One early summer constellation is **Bootes** the Herdsman, rich in double and variable stars but devoid of other types of Milky Way material, with the exception of a lone globular cluster. Although you'll have to put some effort into finding some of these relatively dim objects, the constellation has interesting sights in store for you and your telescope.

The best-known object in the constellation is **Arcturus**, at magnitude -0.1 the fourth-brightest star in the sky. Telescopically, Arcturus isn't much of a sight — it looks like a bright golden yellow K2-type star — but it is interesting from an astrophysical standpoint. Arcturus is a neighbor of ours, lying at a distance of only 37 light-years; it shines with the light of 115 Suns. Its mass is about four times that of our home star, and its diameter is roughly 34.8 million kilometers — some 25 times that of the Sun. Astronomers have measured the heat we receive on Earth from Arcturus; it approximately equals the heat received from a single candle at a distance of five miles!

Arcturus is a Population II star — an old metal-deficient star from our Galaxy's massive halo — and displays a large annual proper motion. This is because the Sun is moving along with the plane of the Galaxy, while Arcturus is cutting through the galactic plane.

This "Guardian of the Bear" has rich historical associations: in 1635 it became the first normal star other than the Sun to be seen during the day; in 1858 Donati's Comet passed just 20′ from the star (which appeared to become enveloped in the comet's tail); and in 1933 light from Arcturus triggered photoelectric cells and started the Century of Progress exposition in Chicago.

One of the finest double stars in the area is **Epsilon (ε) Bootis**, a pair that shines with a combined magnitude of 2.4. This double shows a fine color contrast: the primary is a magnitude 2.5 yellowish-orange star, while the fifth-magnitude secondary appears blue. The two stars are separated by a distance of some 230 astronomical units, which we see as 2.9″ — enough so the two are fairly easy to split with most backyard telescopes if you use high powers.

Another interesting double star is **Xi (ξ) Bootis**, a pair discovered by William Herschel in 1780. This star is one of the most attractive doubles in the area, combining a fifth-magnitude yellow primary and a seventh-magnitude violet secondary. They are separated by 7″ and are thus easy to split in most telescopes; the actual separation of the two stars is about 33 astronomical units, far closer than Epsilon Bootis. According to astrometric studies of this system, an unseen companion rotates around one of the two bright stars — it may be a faint body as small as 0.1 solar masses. If so, it is lost in the glare of the two brighter stars.

44 Bootis is a double star discovered by F.G.W. Struve in 1832. This is a somewhat more complicated system: the primary is very much like our Sun in size, luminosity, and classification, and the dwarf secondary forms a close binary system of its own. The two stars revolve around each other in a remarkably short time: at a distance of about three times that between the Earth and the Moon, the stars complete

one orbit in just over six hours. Together the pair weighs in at just about 1.5 solar masses; both stars resemble our Sun in spectral type.

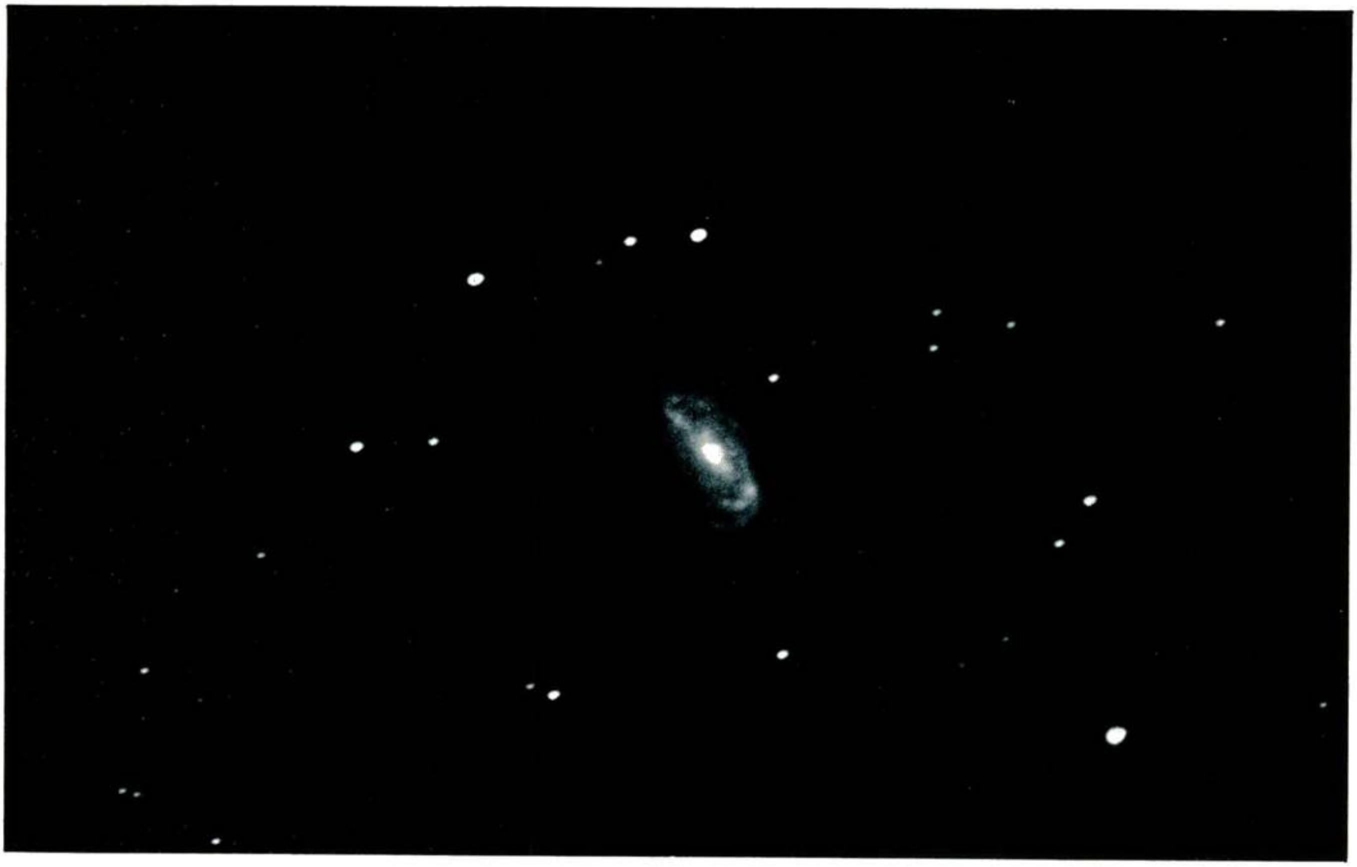
This type of system may be related to the strange class of dwarf novae such as SS Cygni and U Geminorum. An apparent exchange of gaseous material is taking place between stars of this type, and they continue to intrigue astronomers.

A strange irregular variable star, **T Bootis** is also known as Nova Bootis 1860. The only definitive set of observations of this nova were made by Joseph Baxendell in 1860, when the object appeared to be of 10th magnitude on the night of April 9. In two weeks the star faded to magnitude 13 and then disappeared from view, invisible even in a 13-inch telescope. The star has never been seen again — it doesn't show up on modern photographic plates that probe down to 17th magnitude.

In 1953 Joseph Ashbrook suggested that the star may be a recurrent nova, in which case several outbursts have been missed — and more may yet occur. Keep your eyes open when you observe the immediate area in Bootes.

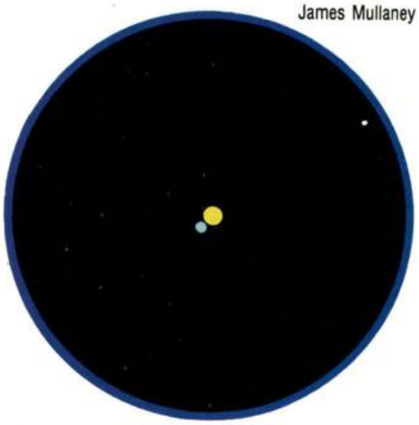
A number of faint galaxies lie in this region of the sky. One of the most interesting is the Sc-type spiral **NGC-5248**, an 11th magnitude object that shows knotty arms laden with dark dust patches. If you observe this galaxy on a dark night using at least a 12-inch scope, you may get a nice view of some of the galaxy's internal structure. Spread out over a 3.2' x 1.4' area, it has a fairly low surface brightness, so use relatively high powers.

To get a good view of other galaxies in Bootes, you'll need a large scope; most of the others shine at 12th magnitude and fainter and are pretty small objects. **NGC-5676** is a 12th magnitude Sc-type spiral that measures 3.0' x 1.5'; an 8-inch scope will show the galaxy as a faint fuzzy patch with no detail. **NGC-5660** is a slightly fainter Sc-type galaxy that is also a little smaller than 5676 — at least a 10-inch is required to see much of anything when you observe this object. Fainter still is **NGC-5600**, a magnitude 12.5 Sc-type spiral that measures only 1' across: the object may look nice in a 20-inch scope, but it probably will disappoint you if you've got anything less. Shining at about the same apparent brightness is **NGC-5899**, an Sb galaxy that spans 2.5' x 0.5' across and has a very low surface brightness. Again, unless you've got dark skies and a large scope, this object will not impress you. A final galaxy in Bootes is **NGC-5687**, a 13th magnitude



NGC-2903 is a type Sc spiral galaxy in Leo that contains many dust lanes and bright knots. At ninth magnitude, it can be seen in scopes of even medium apertures. Thomas Eby took its photograph on hypered 2415 film with a 30-minute exposure at f/5, using an 8-inch SCT and a focal reducer.

James Mullaney



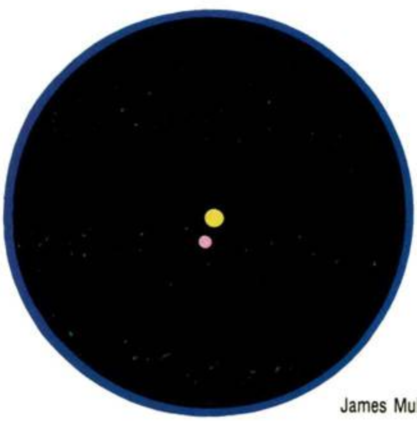
Epsilon Boo **8-inch 200x**

lenticular transition spiral only half an arcminute across. You'll need a 12-inch scope to even *detect* this one.

Finally, we have one Milky Way globular in the constellation. **NGC-5466** is a fairly nice sight in most amateur telescopes. It shines at magnitude 9, covers a 5′ area, and is a very "loose" globular; hence it is hard to detect in small telescopes when the seeing isn't good. Its stars are 11th magnitude and fainter, and it has a pretty low surface brightness for a cluster. Use your wide-field, low-power eyepiece when searching for 5466, and you should be rewarded with a fine view of a typically faint, loose globular.

Although Bootes isn't particularly rich in deep-sky treasures, it does contain some interesting telescopic targets. It deserves to be scanned for interesting doubles and, if you have the right kind of instrument, faint galaxies. Remember that the brightest, most eye-catching objects are not always the most interesting: they may be flashier to show your friends, but some of the most intriguing processes in the universe are happening very subtly, in areas of the sky that we often might overlook.

Xi Boo **8-inch 150x**



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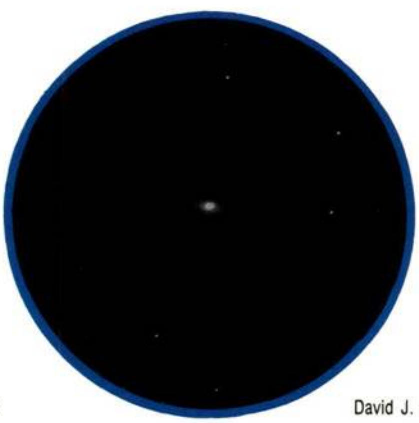
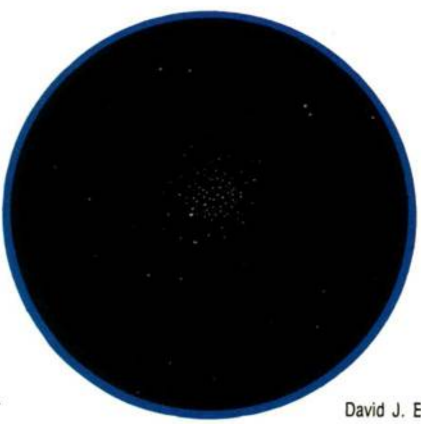
NGC-5248 **8-inch 100x**



David J. Eicher

NGC-5466 **8-inch 70x**

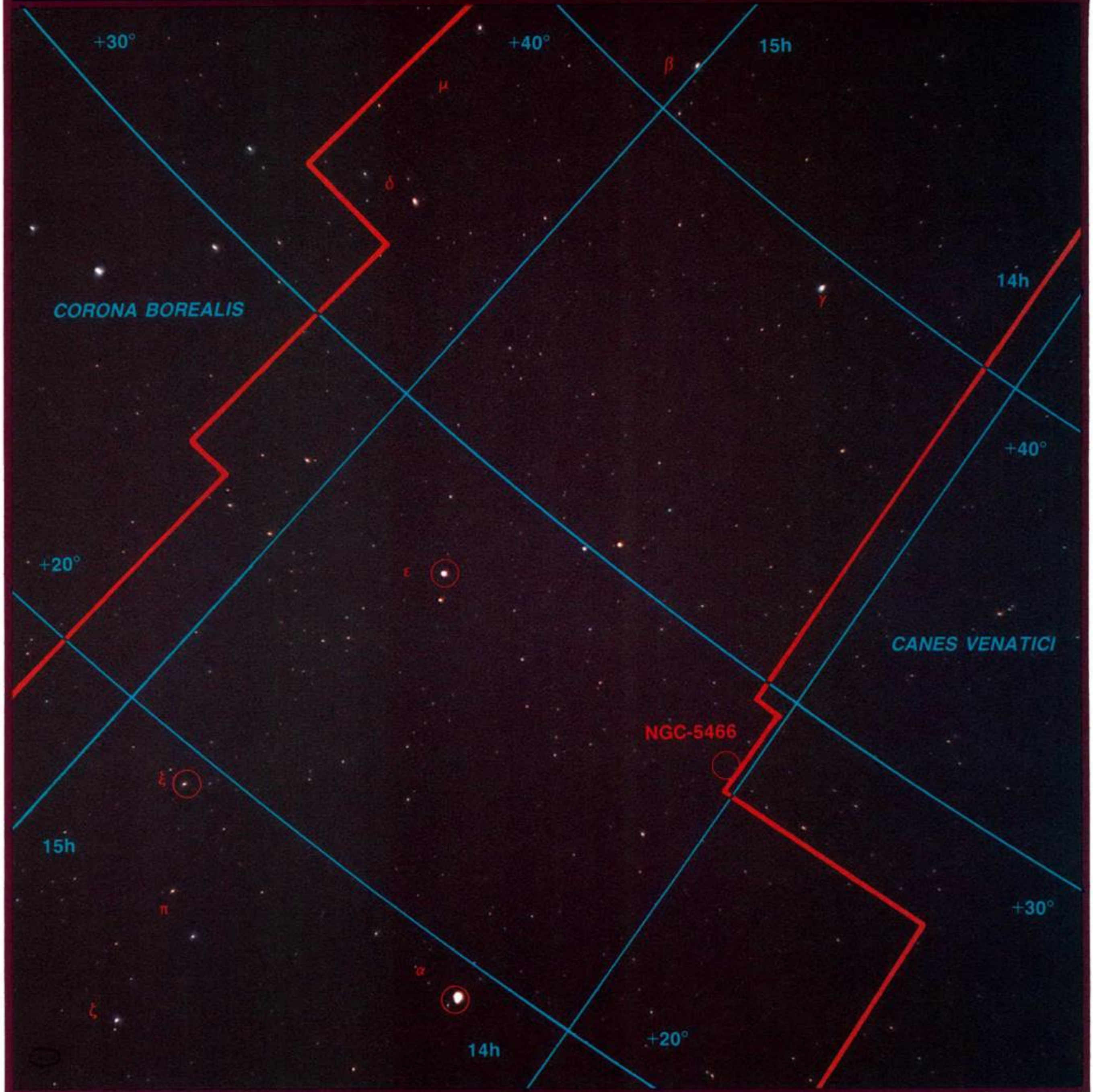


David J. Eicher

Photo by W.P. Duffey, Jr.

bootes

Map by David J. Eicher



Object	Type	Mag.	Size/Sep. Per.	R.A. (1950)	Dec.	R.A. (2000)	Dec.
NGC-5248	§	11.0	3.2′x1.4′	13h 35m	+09°08′	13h 38m	+08°53′
NGC-5466	●	9.0	5.0	14h 03m	+28°46′	14h 05m	+28°32′
T	IV	9.7	—	14h 12m	+19°18′	14h 14m	+19°05′
α	★	−0.1	—	14h 13m	+19°27′	14h 16m	+18°13′
NGC-5600	§	12.4	1.0′x0.9′	14h 21m	+14°52′	14h 24m	+14°38′
NGC-5660	§	12.3	2.2′x2.2′	14h 28m	+49°50′	14h 31m	+49°37′
NGC-5676	§	11.9	3.0′x1.5′	14h 31m	+49°41′	14h 32m	+49°28′
NGC-5687	§	12.7	0.6′x0.4′	14h 33m	+54°42′	14h 35m	+54°29′
ε	★^{2}	2.5+	2.9″	14h 43m	+27°17′	14h 45m	+27°04′
ξ	★^{2}	4.7+6.8	6.9″	14h 49m	+19°18′	14h 52m	+19°06′
44	★^{2}	5.5+6.0	0.5″	15h 02m	+47°51′	15h 04m	+47°39′
NGC-5899	§	12.4	2.3′x0.6′	15h 13m	+42°14′	15h 15m	+42°03′

★	*Star*
★^{2}	*Double Star*
★^{3}	*Triple Star*
RV	*Regular Variable*
IV	*Irregular Variable*
EV	*Eclipsing Variable*
⊙	*Open Cluster*
●	*Globular Cluster*
■	*Planetary Nebula*
□	*Bright Diffuse Nebula*
0	*Elliptical Galaxy*
§	*Spiral Galaxy*
∮	*Barred Spiral Galaxy*
#	*Peculiar/Irregular Galaxy*

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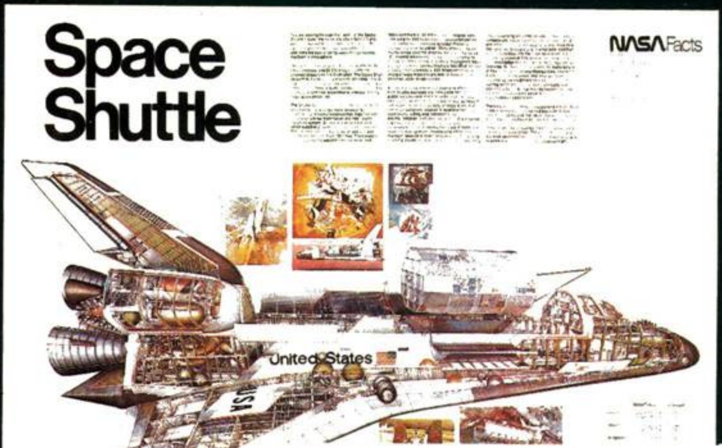

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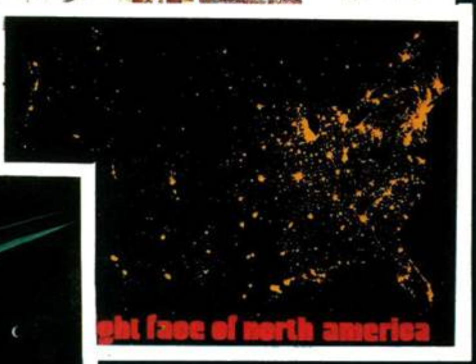

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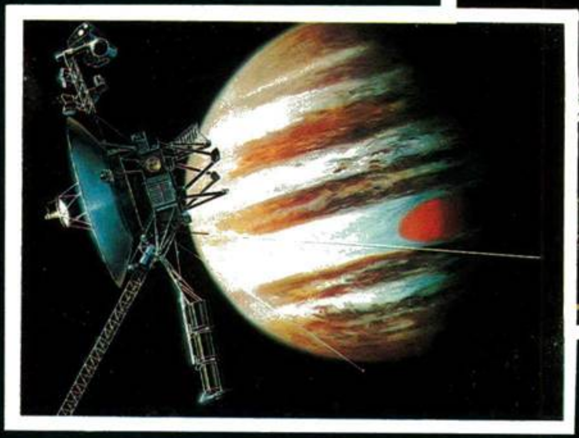

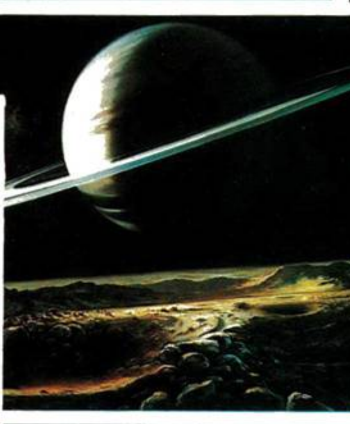

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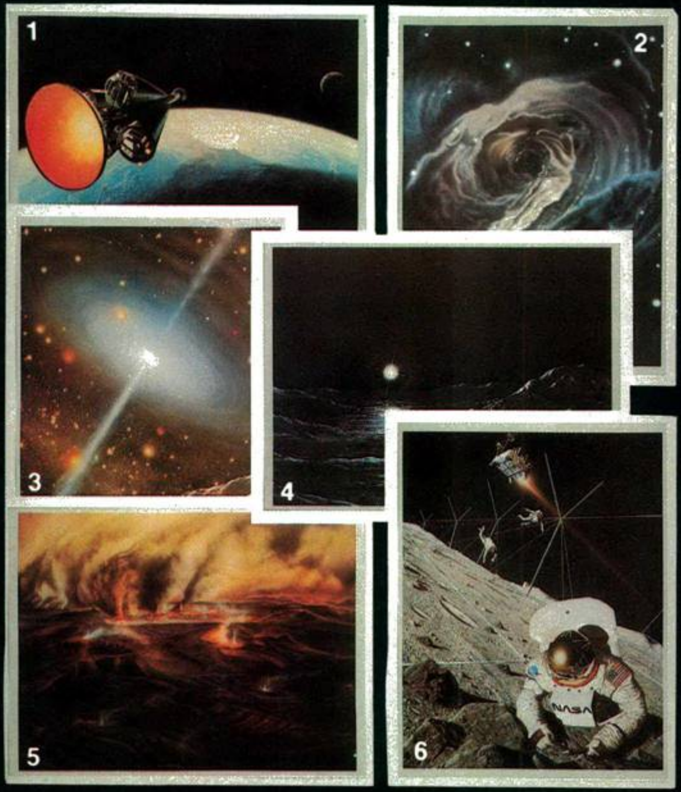

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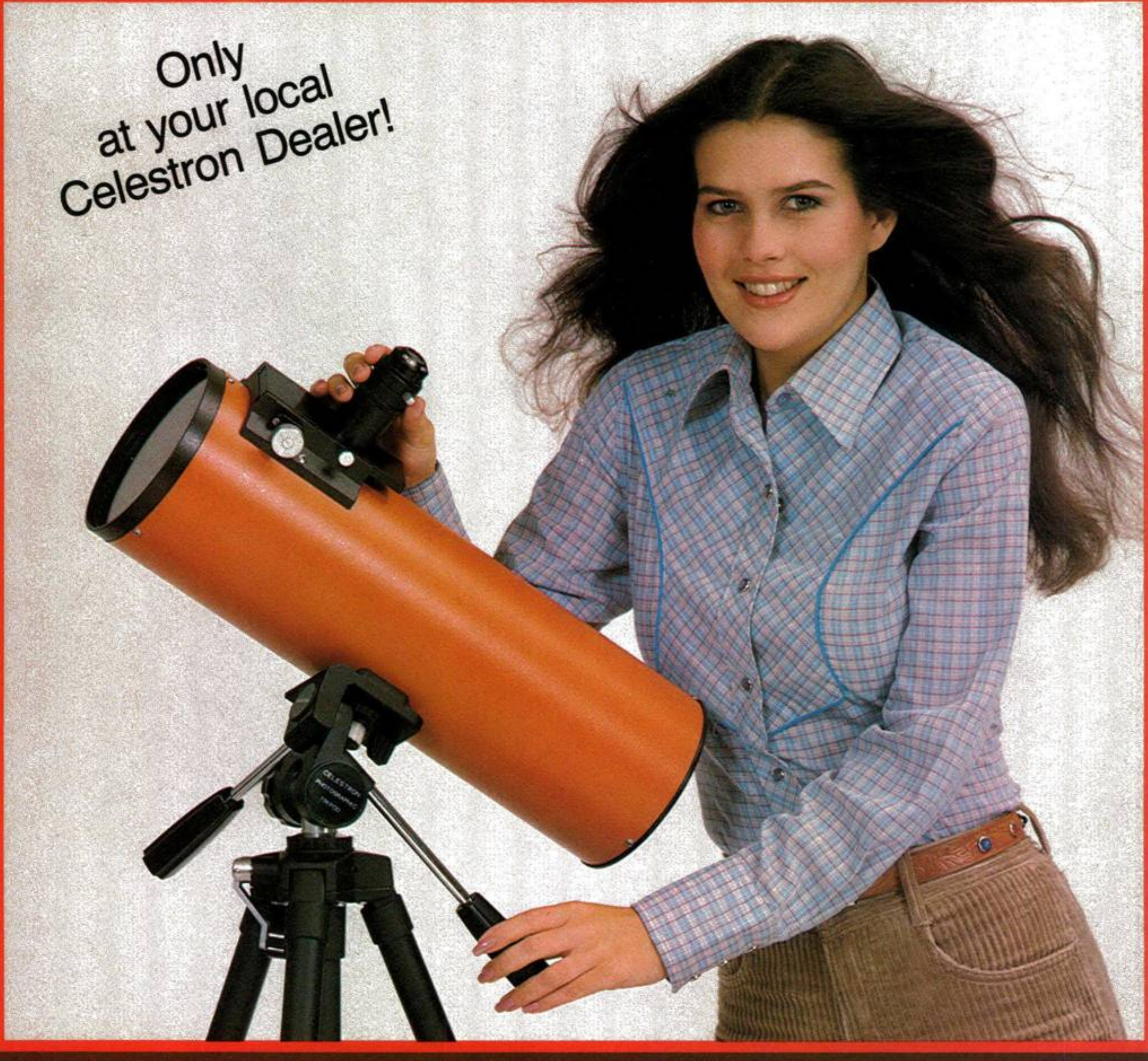

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